X-662-70-346
PREPRINT

NASA TM X- 65335

TECHNIQUES FOR GAMMA RAYS

CARL C. FICHTEL

SEPTEMBER 1970

GSFC — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

TECHNIQUES FOR GAMMA RAYS

Carl E. Fichtel

NASA/Goddard Space Flight Center
Greenbelt, Md., U.S.A.

Invited paper presented at I.A.U. Symposium No. 41 on New Techniques in Space Astronomy, Munich, Germany, August 10-14, 1970.

TECHNIQUES FOR GAMMA RAYS

Carl E. Fichtel

NASA/Goddard Space Flight Center
Greenbelt, Maryland

As Dr. Clark has indicated in his talk, physicists have recently made an increasingly great effort to detect the highest energy photons (those with energies exceeding a few tenths of a MeV) arriving from space. The study of these quanta is necessarily a very new field of astrophysics because the short path length of these photons in air generally demands that the observing instrument be placed above most of the atmosphere. Accordingly, the majority of our information about gamma rays has come from a variety of detectors flown on high altitude balloons (typically at 130 to 140 thousand feet above the surface of the earth) and from small satellite experiments. In this talk, I shall review the types of instruments that have been used in the past and then describe those which will be flown in the future or at least are being proposed. I wish first to thank all of those who have sent me prints of their experiments, and also to express regret that time limitations will not permit me to mention all of the experiments in the field.

The detecting systems used in high energy astrophysics are generally more similar to particle detectors than to optical devices. The high frequency of the radiation precludes the use of reflection or diffraction techniques; however, the high energy content of each photon does enable them to be detected with scintillators, proportional

counters, and solid state detectors. The basic design of the space gamma ray instrument depends on whether the energy range is below about 10 MeV and therefore in the region where the Compton effect predominates in the absorption of the gamma ray, or above that energy where electron-positron pair production is most important. Fig. 1 shows the cross section for γ-rays as a function of energy.

The most usual approach to the detector system in the lower of the two energy intervals is to use a scintillation counter, which absorbs the photons and permits a measure of their energy. This counter is surrounded by another detector which is employed as an active anticoincidence shield to discriminate against charged particles, by providing the information that a charged particle has just passed through the system and therefore the central scintillator has not recorded an x-ray pulse. The first successful detection of gamma rays in this energy range was accomplished by Arnold and coworkers (Arnold et al., 1962; Metzger et al., 1964) using a cesium iodide crystal surrounded by a plastic scintillator. In this experiment both detectors were viewed with a single photomultiplier; discrimination between pulses in the two materials was accomplished by taking advantage of the difference in scintillation periods (about 1 μsec in cesium iodide and two orders of magnitude smaller in plastic scintillator). This instrument covered the range from 0.1 to 1 MeV and was omnidirectional. Recently data has been obtained on the galactic background radiation from 0.25 to 6 MeV using the detector shown in Fig. 2 flown on ERS-18 (Peterson et al., 1968). It consists of a 7.65 cm long x

6.35 cm diameter NaI(Tℓ) scintillation counter with a 1 cm thick plastic anticoincidence shield. There are six channels of pulse height analysis. The anticoincidence scintillator is commutated on and off every 500 seconds. The two scintillators are optically separate.

An instrument which has some directionality has been developed by both the Goddard Space Flight Center group under K. Frost and the University of California at San Diego under L. Peterson. In this detector system a thick collimating wall made of both active and passive material surrounds a central crystal. An example of this type of instrument designed by Frost and Rothe (1963) and flown on OSO is shown in Fig. 3. It is sensitive in the energy region from 0.1 to 3 MeV. The large cylinder which is 7 1/4 inches long and viewed by 4 tubes, is an anticoincidence shield for discrimination against gamma rays and charged particles and for suppression of the Compton continuum. At its heart is a spectrometer crystal one inch in diameter and two inches long, made of thallium-doped cesium iodide. It is viewed by an RCA C7151D photomultiplier. This basic approach has also been used by Haymes and co-workers (Haymes et al., 1968a; Haymes et al., 1968b) at Rice in the study of spectra from several source regions. Figs. 4 and 5 show two recent detector systems of this type and Fig. 6 shows the expected sensitivity for one of them. Other detector systems to study this energy range are discussed by Buivan and Vedrenne (1970); Albernhe et al. (1970); and Dean et al. (1970) in papers No. 5, 6, and 7 of this conference.

The energy range from 1 to 10 MeV remains a particularly difficult one. The combination of the low conversion cross section and the nature of the Compton reaction make directional and energy measurements extremely difficult. There appear now to be two possible directions in which experiments may go in the future. One is a small omnidirectional detector placed as far away from other matter as possible to measure the energy spectrum of the diffuse radiation as well as possible. Another is an assembly of a large number of the cylindrical collimators in an effort to increase the sensitivity and yet obtain some angular information.

Before leaving the low energy gamma region, I should perhaps mention two approaches which have not been too fruitful. In general, passive collimating devices made of lead or other material by themselves have proved to be a net disadvantage because of the creation of secondary gamma-rays in the collimator. Another detector system which has not been very successful is the Compton telescope which consists of two separate scintillators placed in coincidence and surrounded by anti-coincidence plastic scintillators. The basic difficulties are background and low detection efficiency.

Balloon observations have generally been made either by mounting the detector system in a gondola which orients the detector as desired or by mounting the detector in a vertical position and letting the source pass overhead. Orientation information has normally been obtained with the use of magnetometers and balloon position information. Fig. 7 shows the balloon gondola system of Haymes at Rice.

In the gamma ray interval above about 10 MeV the only efficient interaction process for gamma rays is the creation of a negatron-positron pair. Information on the direction and energy of the gamma ray must be derived from this pair because the penetration power of gamma-rays and their low flux relative to charged particles and other radiation make shielding difficult and generally undesirable. Early experiments using counter systems and nuclear emulsions flown on balloons detected no celestial point sources of gamma rays above the background. More significant upper limits to possible fluxes from point sources, and an upper limit to the galactic flux, were obtained by Kraushaar and Clark (1962) and Kraushaar et al. (1965) using the scintillator-Cerenkov type detector system shown in Fig. 8 flown on Explorer 11. An improved version of the detector was flown on OSO-III and led to the first certain measurements of celestial γ-rays. The detector of Clark, Garmire, and Kraushaar (1968) flown on OSO-III is shown in Fig. 9. The top sandwich of crystal scintillators acts as both a converter of gamma rays and as part of the telescope defining the solid angle of the incident gamma ray. The other half of the telescope is the lucite Cerenkov detector, which responds to the Cerenkov light produced by one or both of the negatron-positron pair particles produced in the converter, and is in coincidence with the scintillator sandwich. The detector system is surrounded by a large very efficient anticoincidence dome to reject charged particles.

A scintillator-Cerenkov counter gamma ray telescope has also been flown on two satellites, Proton 2 and Cosmos 208, by Bratolyubova-Tsulukidze et al. (1969), who reported results at the Budapest conference last summer. They used a lead glass Cerenkov counter, and with the aid of pulse height analysis, divided their results into three energy bins. Other scintillator-Cerenkov gamma ray telescopes have been flown on OSO-1 by Fazio and Hafner (1967) and on OSO-III by Kaplon and Valentine (1970) from the University of Rochester.

In view of the very low flux of gamma rays and the very high background of charged particles, it has become apparent that more complicated techniques using picture type detectors and large areas were desirable to see gamma ray point sources. Several investigators have now turned to the spark chamber as the heart of a detector system. The spark chamber provides a high discrimination picture type device. An individual deck of the spark chamber detector consists of a series of parallel planes with a gas in between. A high voltage difference may be applied to pairs of these planes when a particle passes through the chamber. The voltages causes a breakdown along the ionized path left by the charged particle, and a spark forms where the particle has just passed through the chamber. The spark chamber has the advantage of being a high information content device which allows the experimenter to separate the negatron-positron pairs from the other events produced by neutral particles. Generally, the spark chamber assembly is surrounded by an anticoincidence system, and is triggered by a scintillator-Cerenkov counter telescope coincidence signal and an anticoincidence signal from the surrounding anticoincidence detector. Fig. 10 shows an

example of an early version of this type of detector system showing the general configuration (Ehrmann, Fichtel, Kniffen, and Ross, 1967).

Several different types of spark chambers have currently been developed and flown on high altitude balloons. The high altitude thin (typically less than a thousandth of an inch) polyethylene balloon of large dimensions (ten to thirty million cubic feet in volume when fully inflated at ceiling) has proved a great asset to gamma ray astronomy in providing a relatively inexpensive way to get above most of the atmosphere and to test detectors in an environment similar to space. Aspect information to $\pm 1/2°$ is normally available and in some cases orientation systems are used. Flight durations of from 6 to 24 hours at ceiling are normal. Figs. 11 and 12 show a balloon just before launch and during ascent.

Four distinctly different types of spark chambers are currently being considered: the conventional optical spark chamber, the vidicon system, the sonic chamber, and the multiwire digitized spark chamber. I shall discuss all of these briefly.

The optical chamber records on film two orthogonal views of the sparks produced along the path of the negatron and positron. An example of this type of detector system developed by Frye and associates at Case Institute is shown in Fig. 13 (Frye and Smith, 1966). The general approach is seen to be similar to the spark chamber telescope described earlier. Optical spark chambers have also been flown by several other groups including the one of Southampton (S. J. Board, A. S. Dean, and D. Ramsden, 1968. The instrument of this group, shown

in Fig. 14, is one of the largest flown on balloons thus far having a sensitive area of about 3600 cm^2. It now has 70 plates each of .01 radiation lengths. Others include those of Cobb et al. (1965) at Rochester, and Niel, Cassignol, Vedrenne, and Bouigue (1969) of France.

The vidicon system developed for TD-1, and also by Fazio and coworkers for balloons (Helmken and Fazio, 1966; Fazio et al., 1968) replaces the film with a vidicon tube which then records the spark "picture" electronically and the information may be stored on tape or telemetered. The TD-1 program is a joint effort of three institutions under the direction of Pinkau and Sommer at the Max-Planck-Institut für Extraterrische Physik, Koechlin at Saclay, and Boella at the University of Milan. A schematic diagram of the experiment is shown in Fig. 15. The gamma ray telescope has an active area of 130 cm^2. a solid angle of 0.22 sr, and an asymptotic detection efficiency of 25%. The energy threshold is about 50 MeV. The detector will be continuously pointed away from the earth and will therefore have no dead time resulting from being pointed at the earth, but will not have the ability to point at a potential source for long periods. The exposure will be $5 \cdot 10^5$ cm^2 sr sec/day and $2 \cdot 10^5$ cm^2 sec/day for a source in its scanning path.

A somewhat different technique is used in the sonic chamber which uses microphones to record the position of the spark by the use of accurate timing signals. A small version of this type of detector

was the first spark chamber in space, being flown on OGO-E by Hutchinson, Pearce, Ramsden, and Wills (1969). This instrument is shown in Fig. 16.

A sonic spark chamber for a gamma ray telescope was also developed by the Cornell group (Ogelman, Delvaille, and Greisen, 1966) and flown successfully on a balloon.

Another gamma ray gelescope including a spark chamber has recently been flown on Cosmos 264 by Volobuyev et al. (1969). A 4 gap spark chamber was placed under a one radiation length converter, and one of the main objectives of the spark chamber was to see the shower development.

Magnetic core digitized spark chambers have been developed at Goddard Space Flight Center and the Max-Planck Institut fur Extraterrische Physik. In both cases, we were guided in the beginning in part by the excellent work of Krienen at CERN (Krienen, 1962 and 1963). The Goddard and Max-Planck instruments are similar in basic design. A schematic diagram of the magnetic core spark chamber gamma ray telescope developed by the Max Planck group is shown in Fig. 17 (Mayer-Hasselwander, Pinkau, and Sommer, 1970). The second generation 2500 cm^2 γ-ray telescope developed at Goddard Space Flight Center (Ross et al., 1969) is shown schematically in Fig. 18 and with the dome removed in Fig. 19. The GSFC spark chamber itself is shown in Fig. 20. For the digitized spark chamber, the flat plates of each module are replaced by two planes of wires orthogonal to each other. One of

these grids serves as the ground plane and the other as the high voltage plane. A spark between the planes causes a current to flow in the two orthogonal wires connected electrically by the spark setting cores on the ends of the wire. By reading out the cores a picture can be constructed. Such a picture is shown in Fig. 21.

A satellite version of the Goddard detector system will be flown on SAS-B. It is a direct outgrowth of the balloon version flown during 1966 through 1968, except that it employs a four telescope system. This approach maintains directionality and adds reliability by increasing redundancy. The SAS-B detector will have the following characteristics: Effective area, A = 500 cm^2, Ω = 1/4 SR.; Efficiency (high energy) = .29; Efficiency (100 MeV) = .21; live time (pointing away from earth) $\simeq$ .9; fraction of orbit in which detector is not seriously affected by earth albedo = 1/2. The net exposures will be 5 x 10^6 cm^2 sec/day and 1.2 x 10^6 cm^2 sr.sec/day. The angular accuracy is about 1 1/2° at 100 MeV and varies with energy approximately as $E^{-2/3}$. The threshold is not sharp, but is about 20 to 25 MeV. The energy of the γ-ray is measured up to about 200 MeV. An artist's concept of SAS-B is shown in Fig. 22.

It is clear that instruments substantially more sensitive than SAS-B should ultimately be flown. At least two possibilities seem to exist at this time, COS-B and HEAO. For COS-B, it is proposed that a gamma ray detector be the sole experiment on a satellite launched probably into eccentric orbit by a Thor-Delta rocket. It

would be a joint effort by Kammerlingh Onnes Laboratory (Leiden), Max-Planck Institut fur Extraterrestrische Physik, Centre d'Etudes Nucleaires de Saclay, Universita Degli Studi di Milano, and the European Space Laboratory. The instrument would include a series of spark chambers and scintillators surrounded by anticoincidence. The approach and angular resolution would be similar to other spark chamber experiments. The sensitivity would be greater and the energy range on which the energy was determined would be extended to higher energies by using a CsI crystal of large area. Final approval for HEAO and selection of experiments has not yet occurred, but it is likely that gamma ray experiments will be included.

Nuclear emulsions were used on balloons even before spark chambers by Bracessi et al. (1960); Klarman (1962); Frye, Reines and Armstrong, 1966; and Fichtel and Kniffen (1965). More recently nuclear emulsions have been combined with spark chambers by May and Waddington (1969) and Kinzer, Seeman, and Share (1969). The latter use a wide gap spark chamber with emulsions as shown in Fig. 23. The wide gap spark chamber is used for good angular and spatial resolution with a minimum amount of material after entrance from the nuclear emulsion. At present charged particle background seems to make this approach unacceptable for satellite use, even if the recovery problem is solved.

In the high energy region above a few hundred MeV, thought is now being given by Fazio and Greisen to using a gas Cerenkov counter either alone or in conjunction with a large spark chamber. Fig. 24 shows an

example of this approach (Delvaille et al., 1970). A gas Cerenkov counter records the Cerenkov light produced by a relativistic particle (in this case the negatron and positron formed by the gamma ray) whose velocity exceeds that of the speed of light in the gas. The gas Cerenkov counter has the advantages of fairly high directionality, a relatively low background because of the high energy threshold and the directional property, and the potential for very large collection areas at low cost with little complexity. In this high energy region the electrons scatter relatively little, and, therefore, a relatively thick converter may be used after the anticoincidence shield. The pairs pass through a scintillator and then into the low volume Cerenkov gas at angles within a degree or two of their original direction. Helmken and Hoffman (1970) are also giving consideration to applying the gas Cerenkov approach to lower energies.

At extremely high energies (above about 10^6 MeV), photons can be detected by instruments at sea level which record the cascade shower particles or the Cerenkov light produced in the atmosphere from a series of interactions initiated by a single incident gamma ray. In the latter case, the negatron and positrons in the shower emit Cerenkov light and the direction of the emitted light corresponds very nearly to the direction of the gamma ray as it enters the atmosphere. Fig. 25 shows the 10-meter optical reflector of Smithsonian Astrophysical Observatory, Mt. Hopkins, Arizona. This approach is complicated by the fact that high energy charged particles also produce cascade showers.

A gamma ray source could, however, be detected by the observation of a marked increase in flux from some direction, or by distinguishing between the types of particle showers as some of the more complex ground instruments may be able to do.

The future hope of high energy gamma ray astronomy appears to lie in getting the large new detectors onto satellites. The size of the system seems to indicate that they must fly as the major experiment on an explorer or together with other experiments on a very large spacecraft. If current plans are realized, gamma ray experiments of this large scale should be flown in the near future. The valuable information on nature's high energy processes should then begin to be revealed in detail.

REFERENCES

Albernhe, F., Doulade, C., Martin, I. M., Talon, R., and Vedrenne, G. I.A.U. Symposium No. 41, Paper 6 (1970).

Arnold, J. R., Metzger, A. E., Anderson, E. C., and Van Dilla, M. A., J.G.R., Vol. 67, p. 4878 (1962).

Board, S. J., Dean, A. J., and Ramsden, D., Nucl. Inst. and Methods, 65, 141 (1968)

Bracessi, A., Ceccarelli, M., and Salandin, G., Nuovo Cimento 17, 691 (1960).

Bratolyubova-Tsulukidze, L.I., Grigorov, N. L., Kalinkin, L. F., Melioransky, A. S., Pryakhin, E. A., Savenko, I. A., and Yufarkin, V. Y., Paper OG-20, Eleventh International Conference on Cosmic Rays, Budapest, Hungary, Aug. 25-Sept 4 (1969).

Buivan, A., and Vedrenne, I.A.U. Symposium No. 41, Paper 5 (1970).

Clark, G., Garmire, G., and Kraushaar, W., Ap. J. (Letters) Vol. 153, L203 (1968).

Cline, T. L., Phys. Rev. Letters 7, 109 (1961).

Cobb, R., Duthie, J. G., and Stewart, J., Phys. Rev. Letters 15, 507 (1965).

Dean, A., Bellomo, A., Coffaro, P., Gerardi, G., Madonia, F., Russo, A., and Scarsi, I.A.U. Symposium No. 41, Paper 7 (1970).

Dean, A. J., Hutchinson, G. W., Ramsden, D., Taylor, B. G., and Wills, R. D., Nucl. Inst. and Methods 65, 293 (1968).

Delvaille, J., Fazio, G., Greisen, K., Hearn, D., Koch, D., Helmken, H., McBreen, B., I.A.U. Symposium No. 41, Paper 9 (1970).

Ehrmann, C. H., Fichtel, C. E., Kniffen, D. A., and Ross, R. W., Nucl. Instr. and Methods 56, 109 (1967).

Fazio, G. G., and Hafner, E. M., J. Geophys. Res. 72, 2452 (1967)

Fazio, G. G., Helmken, H. F., Carrah, Jr., S. J., and Hearn, D. R., Canadian Journal of Physics 46, S 427 (1968).

Fichtel, C. E., and Kniffen, D. A., J. Geophys. Res. 70, 4227 (1965).

Frost, K. J. and Rothe, E. D., NASA Tech. Note D-1693 (1963).

Frye, G. M., Reines, F., and Armstrong, A. H., J. Geophys. Res. 71, 3119 (1966).

Frye, G. M., and Smith, L. H., Phys. Rev. Letters 17, 733 (1966).

Haymes, R. C., Ellis, D. V., Fishman, G., Kurfess, J. D., and Tucker, W. H., Ap. J. (Letters), 151, L9 (1968a).

Haymes, R. C., Ellis, D. V., Fishman, G. J., Glenn, S. W., and Kurfess, J. D., Ap. J. (Letters), 151, L125 (1968b).

Helmken, H. F., and Fazio, G. G., IEEE Trans. Nucl. Sci. NS-13, 486 (1966).

Helmken, H. and Hoffman, J., I.A.U. Symposium No. 41, Paper 10 (1970).

Hutchinson, G. W., Pearce, A. J., Ramsden, D., and Wills, R. D., I.A.U. Symposium No. 37 (1969).

Kaplon, M. F., and Valentine, D., Acta Phys. Aca. Sci. Hungaricae 29, Suppl. 1 (in press) (1970).

Kaplon, M. F., and Valentine, D., 11th Internation Conf. on Cosmic Rays, Paper OG-19 (1969).

Kinzer, R. L., Seeman, N., and Share, G. H., Nucl. Inst. and Methods 76, 70 (1969).

Klarmann, J., Nuovo Cimento 24, 540 (1962).

Kraushaar, W. L., and Clark, G. W., Phys. Rev. Letters 8, 106 (1962).

Kraushaar, W., Clark, G., Garmire, G., Helmken, H., Higbie, P., and Agogino, M., Ap. J., 141, 845 (1965).

Krienen, F., Nucl. Instr. and Methods 20, 168 (1963).

Krienen, F., Nucl. Instr. and Methods 16, 262 (1962).

Mayer-Hasselwander, K. Pinkau, and M. Sommer, Private Communication (1970).

Metzger, A. E., Anderson, E. C., Van Dilla, M. A., and Arnold, J. R., Nature, 204, 766

Niel, M., Cassignol, M., Vedrenne, G., and Bouigue, Nucl. Inst. and Methods 69, 309 (1969).

Ogelman, H. B., Delvaille, J. P., and Greisen, K. I., Phys. Rev. Letters 16, 491 (1966).

Peterson, L. E., Gruber, D., Lewis, S. J., Stone, M. R., and Vette, J. I., Univ. of Calif. at San Diego Report UCSD-SP-68-5 (1968).

Ross, R., Ehrmann, C., Fichtel, C., Kniffen, D., and Ogelman, H., IEEE Trans. on Nuclear Science, NS-16, 127 (1969). Also GSFC X-611-68-443).

Volobuyev, S. A., Galper, A. M., Kirillov-Ugryumov, V. G., Luchkov, B.I., Yu, Ozerov, V., Rozental, I. L., Shermanzon, E. M., Grigorov, N. L., Kelinkin, L. F., Malioransky, A. S., Savenko, I. A., and Shashko, T. A. , 11th International Conf. on Cosmic Rays, Paper OG 20 (1969).

FIGURE CAPTIONS

Fig. 1: Interaction coefficient for gamma rays as a function of energy for lead. The point where the Compton curve crosses the pair production curve depends somewhat on the material.

Fig. 2: Low energy gamma ray detector (0.25 to 6 MeV) flown by Vette, Gruber, Matteson, and Peterson on ERS-18.

Fig. 3: Low energy gamma ray detector designed by Frost and Rothe flown on OSO-3.

Fig. 4: A current low energy gamma ray detector being developed by Peterson and co-workers.

Fig. 5: A low energy gamma ray detector to be flown on OSO-I by Frost and co-workers.

Fig. 6: Sensitivity of the OSO-I experiment shown in the previous figure as a function of energy compared to the x-ray flux from representative sources.

Fig. 7: Balloon orientation system used by Haymes and co-workers at Rice University.

Fig. 8: High energy scintillator-cerenkov detector flown on Explorer 11 by Kraushaar and co-workers.

Fig. 9: High energy gamma ray detector flown by Clark, Garmire, and Kraushaar on OSO-III. This instrument led to the first certain measurement of gamma rays.

Fig. 10: Schematic diagram of the original small version of the Coddard digitized spark chamber gamma ray telescope.

Fig. 11: A balloon just before release at Mildura, Victoria, Australia.

Fig. 12: The same balloon as in Fig. 11 rising through the atmosphere carry a high energy gamma ray detector of the Goddard Space Flight Center.

Fig. 13: High energy optical film spark chamber telescope developed by Frye and co-workers at Case.

Fig. 14: High Energy optical film spark chamber gamma ray telescope built by Ramsden and co-workers at Southampton.

Fig. 15 High energy gamma ray vidicon spark chamber telescope to be flown on TD-1 by the Max-Planck Institut fur Extraterrestrische Physik, Center d'Etudes Nucleaires de Saclay, and the Universita Degli Studi di Milano.

Fig. 16: High energy gamma ray sonic spark chamber flown by Hutchinson et al. (1969) on OGO-E.

Fig. 17: Schematic diagram of high energy gamma ray magnetic core digitized spark chamber telescope developed at Max-Planck Institut by Pinkau and Sommer.

Fig. 18: Schematic design of high energy gamma ray magnetic core digitized spark chamber developed at Goddard by Ehrmann, Fichtel, Kniffen, and Ross.

Fig. 19: Balloon gamma ray experiment of Fig. 18 with anticoincidence dome removed.

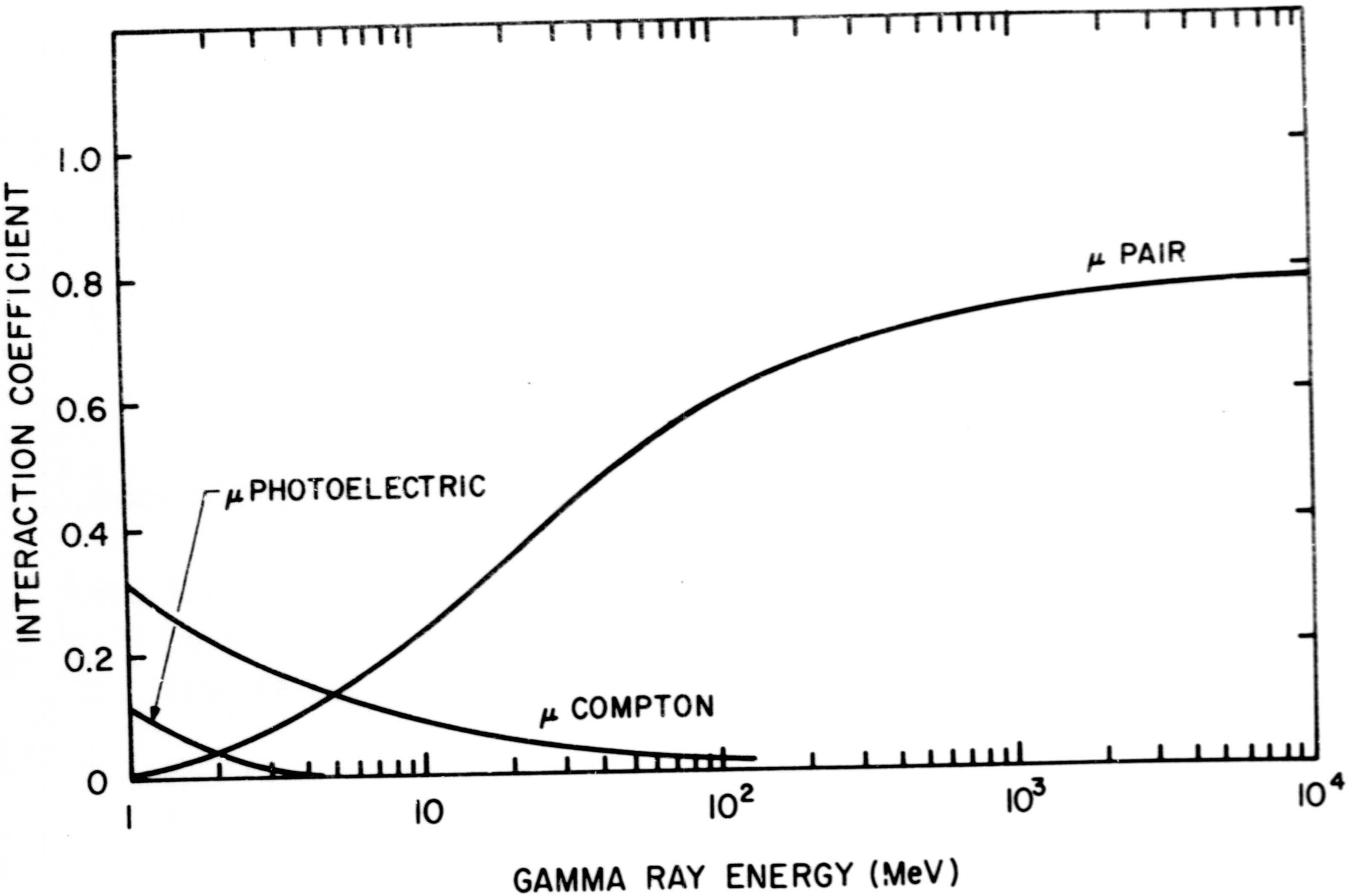

INTERACTION COEFFICIENT
1.0
0.8
0.6
0.4
0.2
0
μ PAIR
μ PHOTOELECTRIC
μ COMPTON
1
10
10^2
10^3
10^4
GAMMA RAY ENERGY (MeV)

Fig. 1

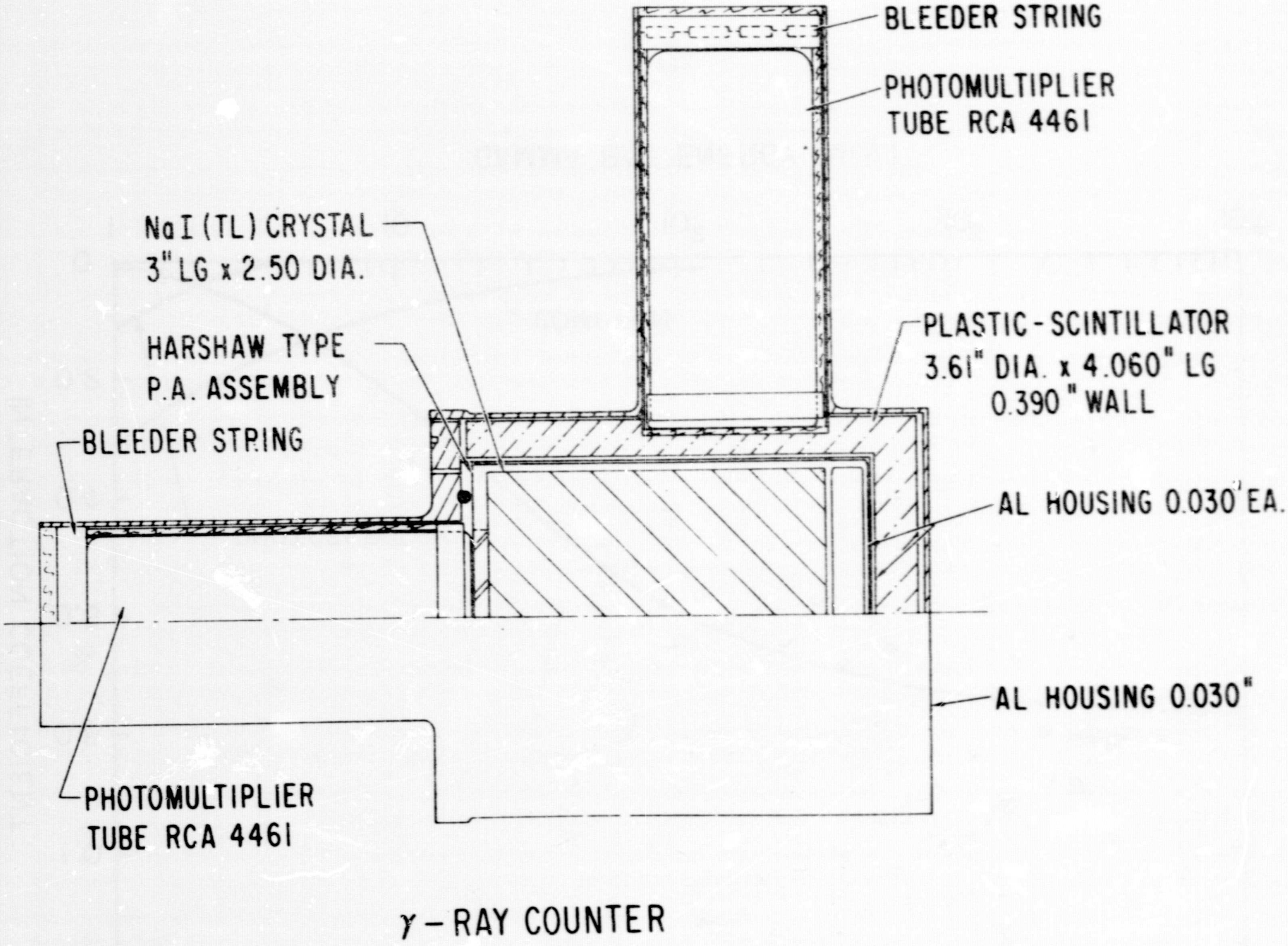
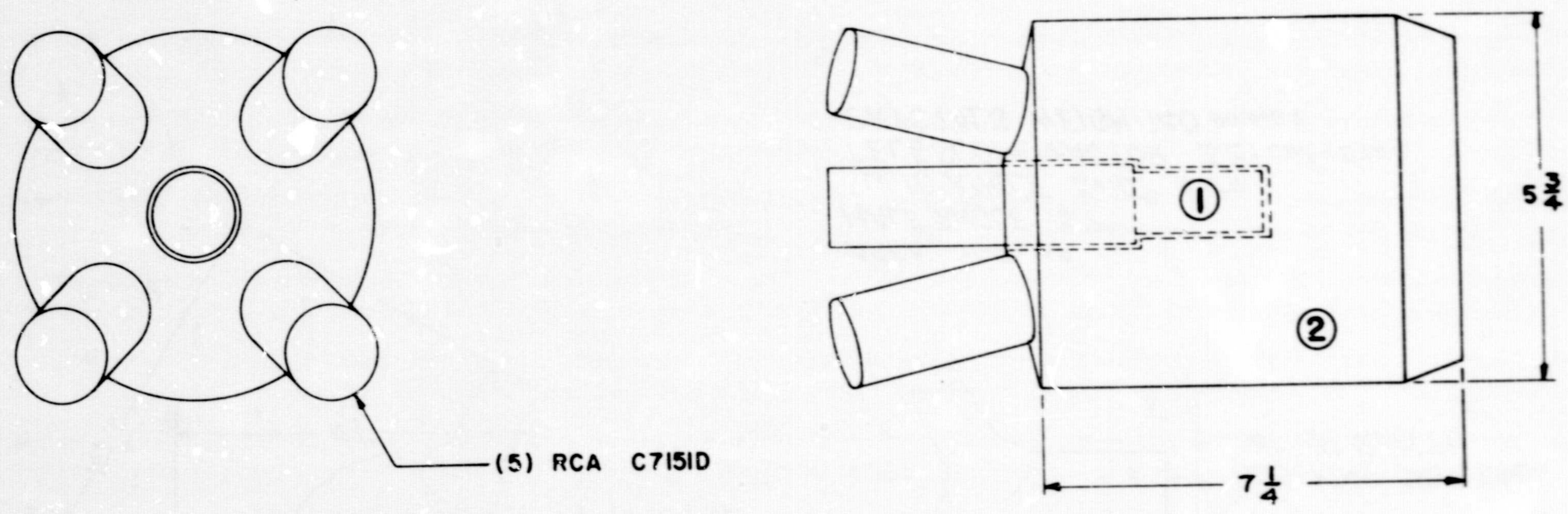

BLEEDER STRING
PHOTOMULTIPLIER TUBE RCA 4461
NaI (TL) CRYSTAL 3" LG x 2.50 DIA.
HARSHAW TYPE P.A. ASSEMBLY
PLASTIC-SCINTILLATOR 3.61" DIA. x 4.060" LG 0.390" WALL
BLEEDER STRING
AL HOUSING 0.030" EA.
AL HOUSING 0.030"
PHOTOMULTIPLIER TUBE RCA 4461
γ-RAY COUNTER

Fig. 2



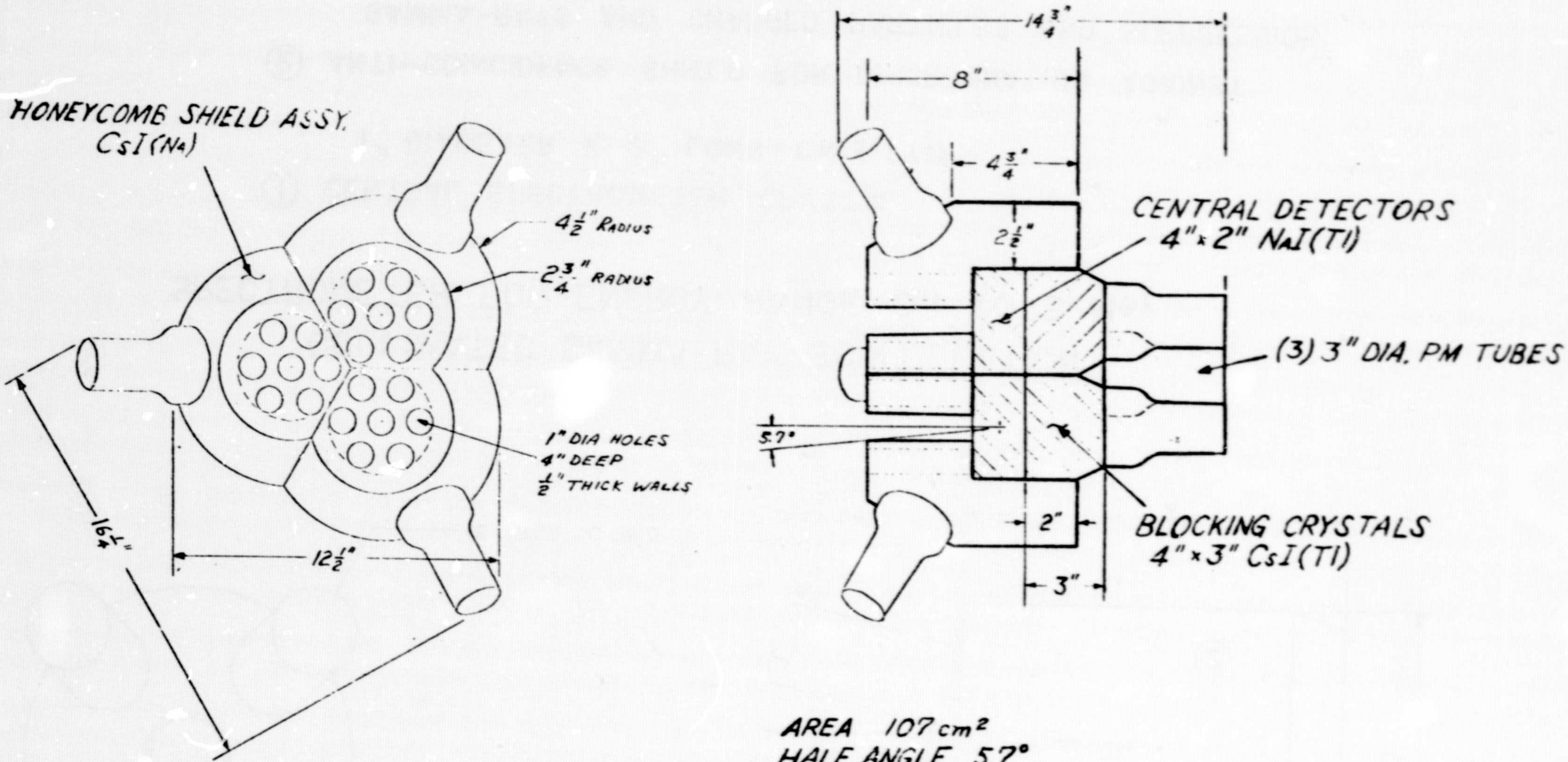
COLLIMATED GAMMA-RAY SCINTILLATION SPECTROMETER FOR ENERGY RANGE 0.1 TO 3 Mev

① CENTRAL SPECTROMETER CRYSTAL
1" DIAMETER X 2" LONG Cs I (Tl).

② ANTI-COINCIDENCE SHIELD FOR DISCRIMINATION AGAINST GAMMA-RAYS AND CHARGED PARTICLES AND SUPPRESSION OF COMPTON CONTINUUM.

Fig. 3

0.3-10 MEV TELESCOPE



AREA 107 cm^2
HALF ANGLE 5.7°
SOLID ANGLE 3×10^{-2} STER.
TELESCOPE FACTOR 3.21 cm^2-STER.
CRYSTALS WEIGH 140 POUNDS

Fig. 4

OSO-I (EYE) 10 KEV - 1 MEV X-RAY DETECTOR

PARAMETERS OF DETECTOR	
SENSITIVE AREA	$56.9\ cm^2$
MAX. ACCEPTANCE ANGLE	6.3°
F W H M	5.1°
AREA × SOLID ANGLE FACTOR	$0.54\ cm^2\ st$
WEIGHT OF CRYSTALS	70 lbs

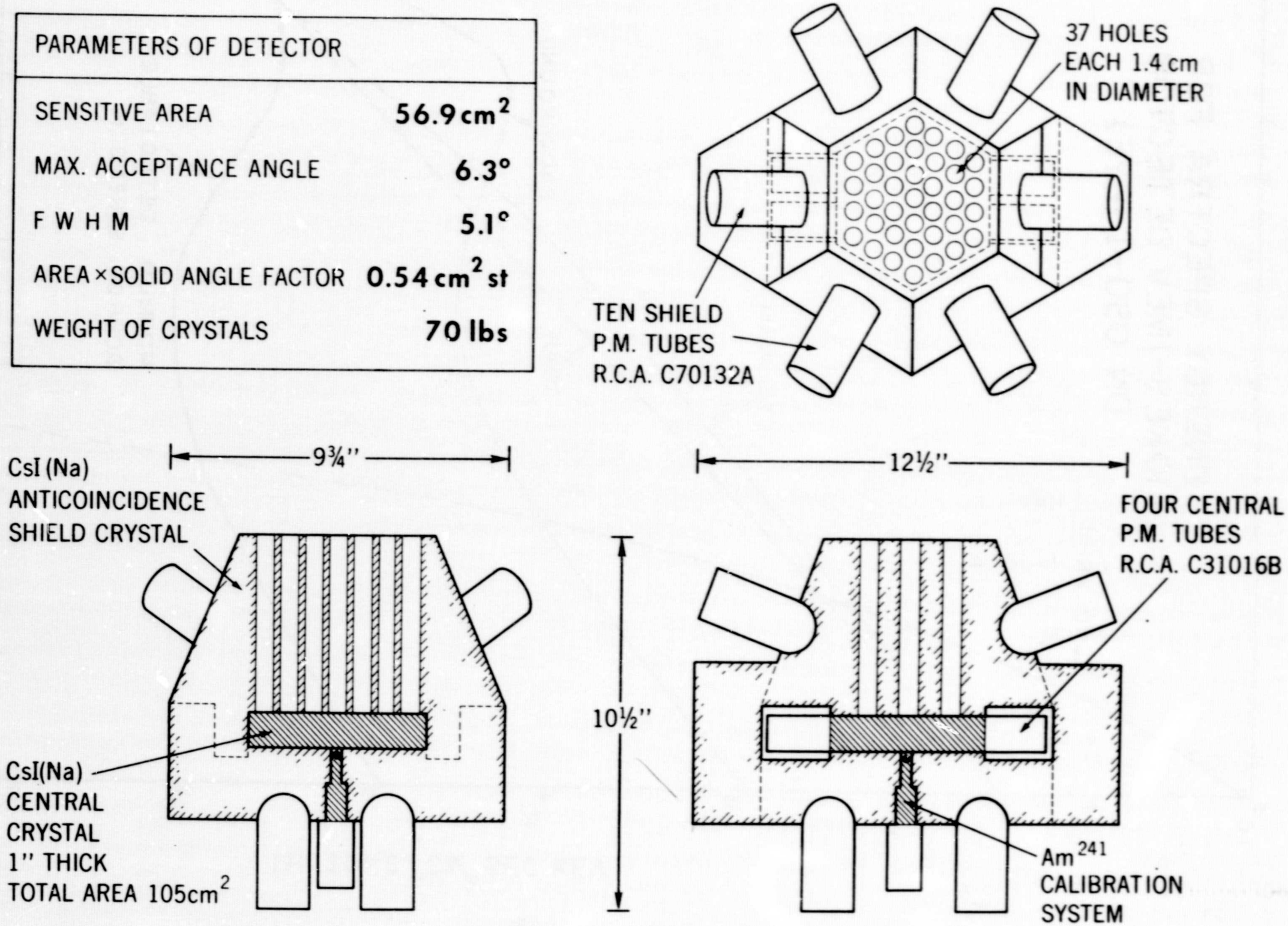
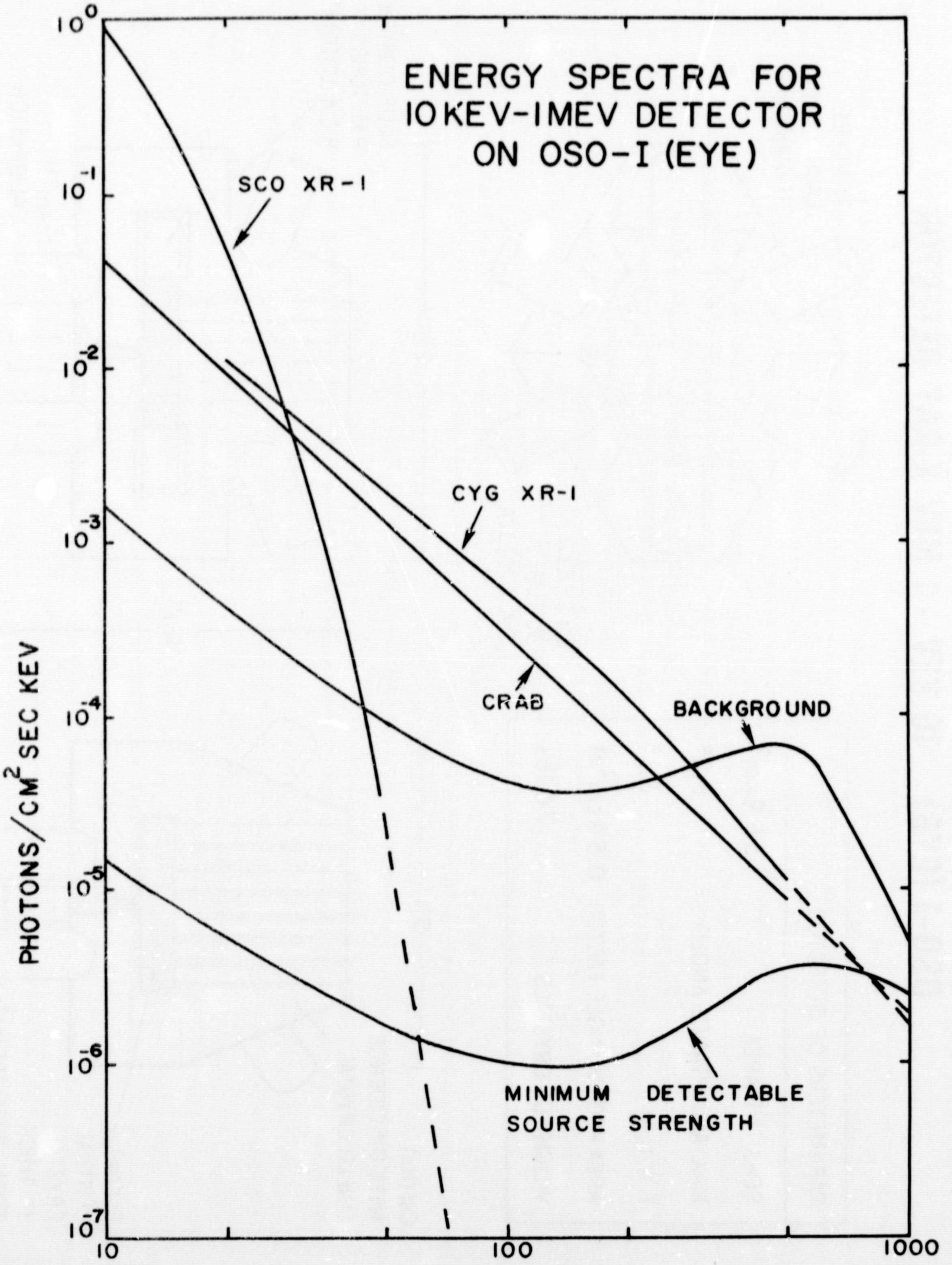
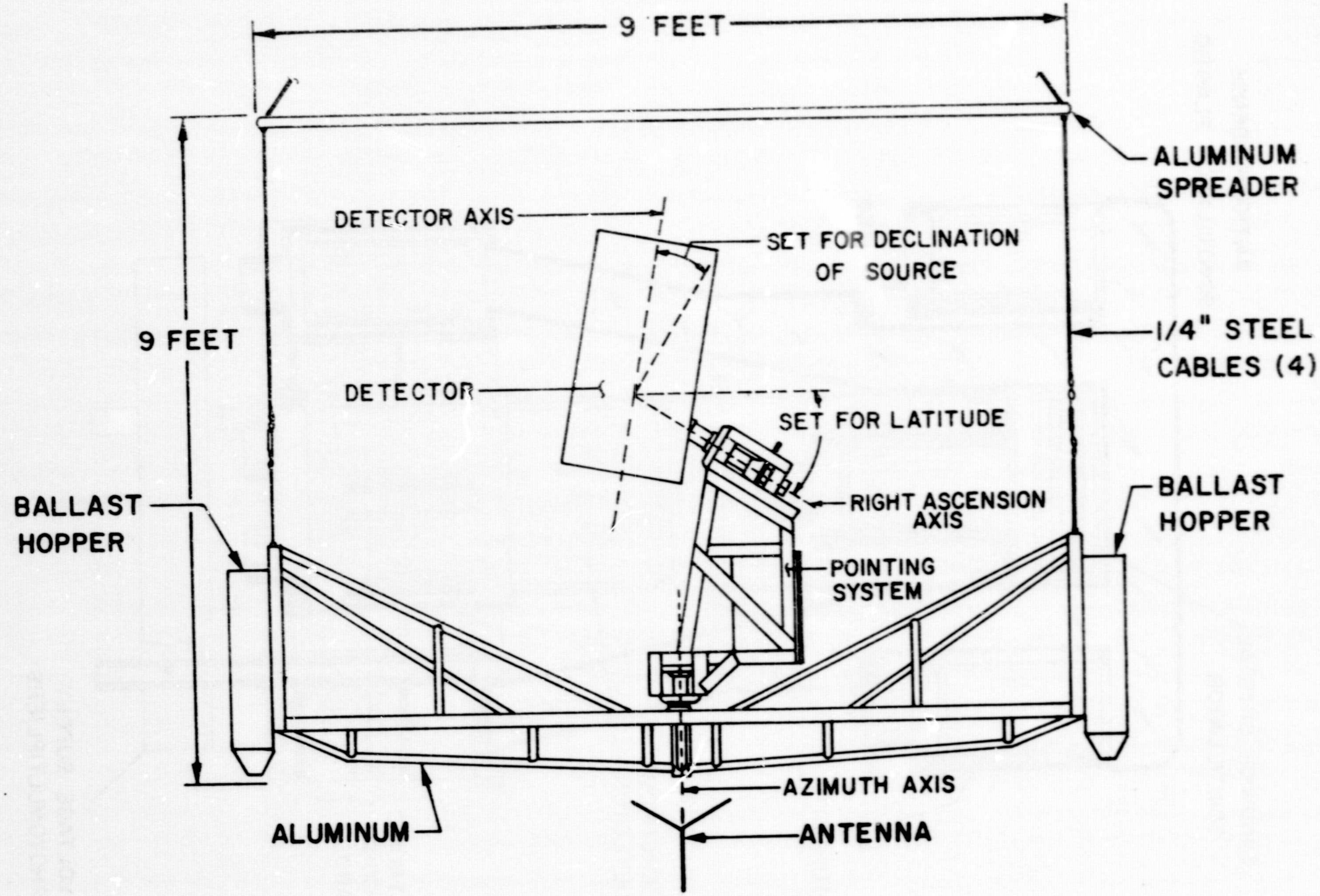


Fig. 5



ENERGY SPECTRA FOR
10 KEV-1MEV DETECTOR
ON OSO-I (EYE)
SCO XR-1
CYG XR-1
CRAB
BACKGROUND
MINIMUM DETECTABLE
SOURCE STRENGTH
PHOTONS/CM^2 SEC KEV
ENERGY IN KEV
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10
100
1000

Fig. 6



RICE UNIVERSITY
BALLOON BORNE SYSTEM

201508

Fig. 7

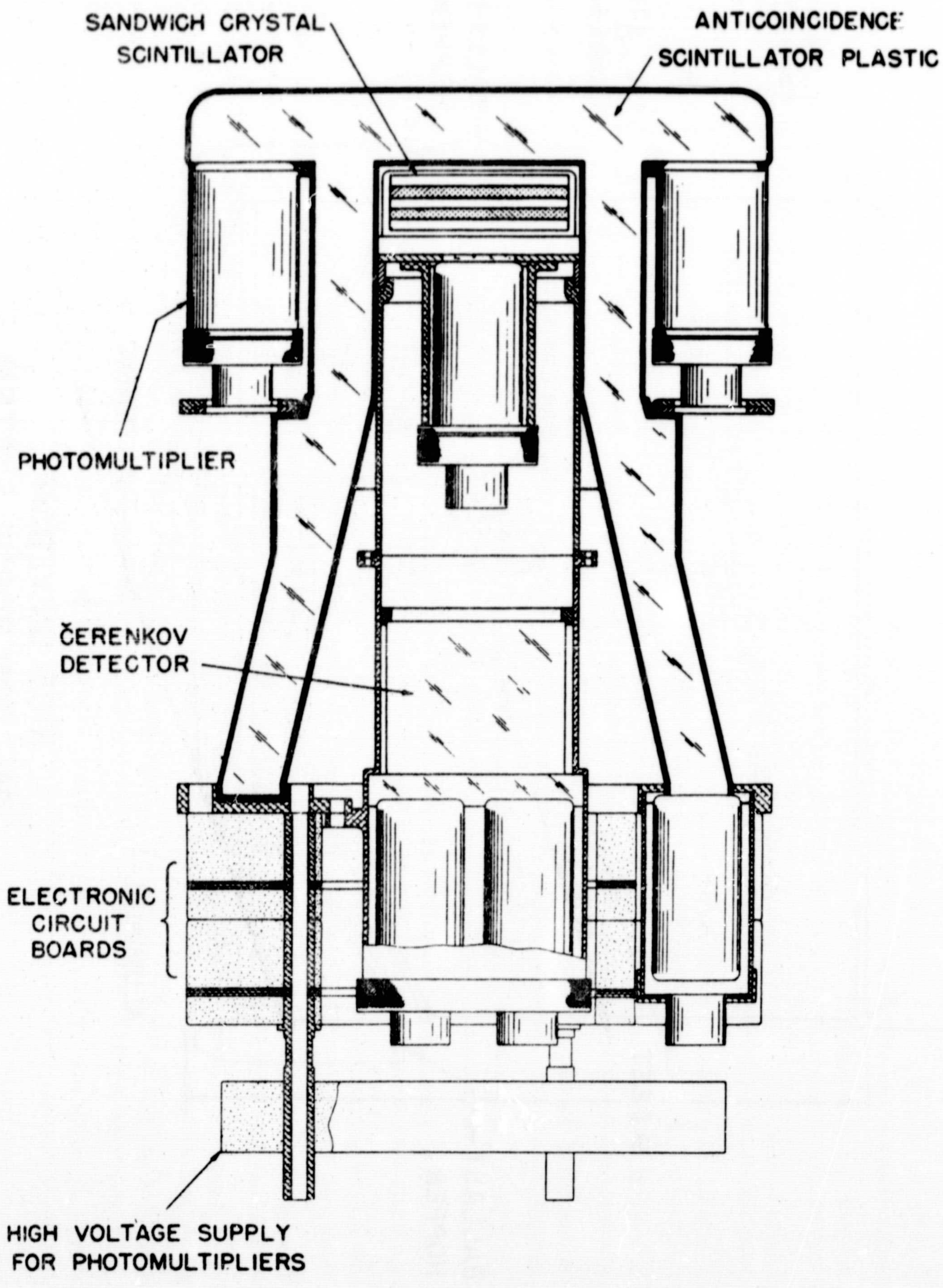
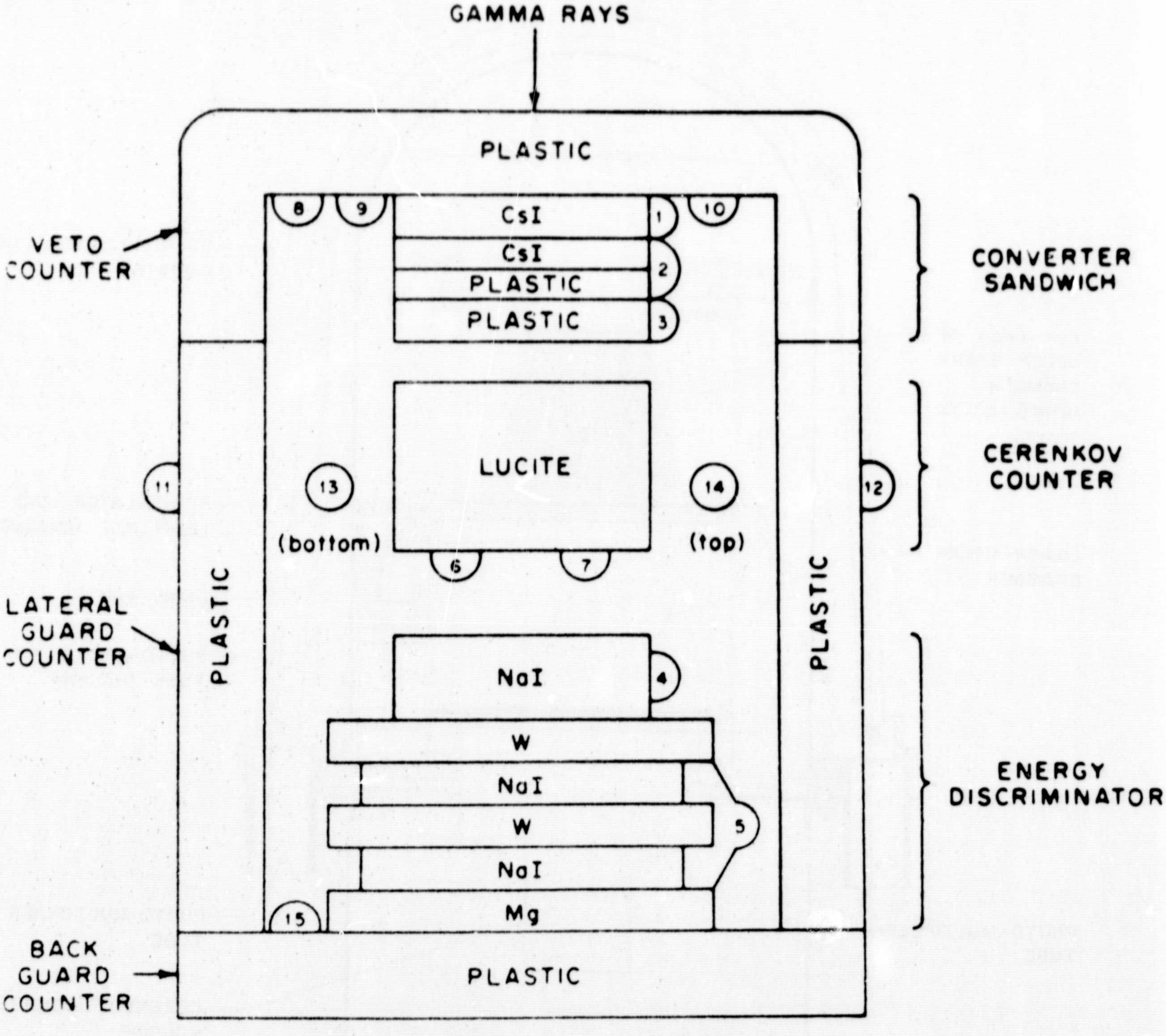

SANDWICH CRYSTAL SCINTILLATOR
ANTICOINCIDENCE SCINTILLATOR PLASTIC
PHOTOMULTIPLIER
ČERENKOV DETECTOR
ELECTRONIC CIRCUIT BOARDS
HIGH VOLTAGE SUPPLY FOR PHOTOMULTIPLIERS

Fig. 8



Schematic diagram of the detector.

Fig. 9

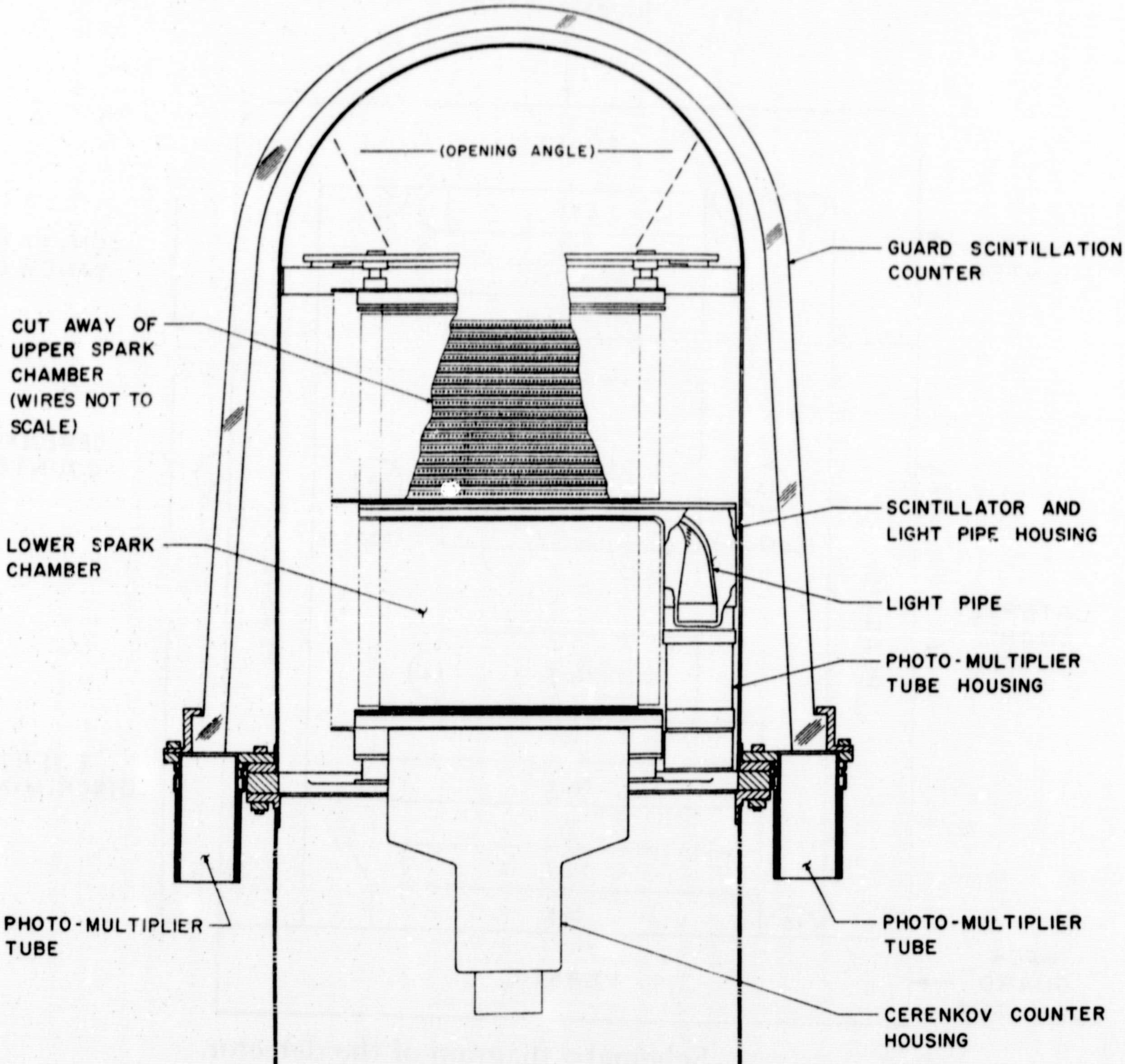

(OPENING ANGLE)
GUARD SCINTILLATION COUNTER
CUT AWAY OF UPPER SPARK CHAMBER (WIRES NOT TO SCALE)
SCINTILLATOR AND LIGHT PIPE HOUSING
LOWER SPARK CHAMBER
LIGHT PIPE
PHOTO-MULTIPLIER TUBE HOUSING
PHOTO-MULTIPLIER TUBE
PHOTO-MULTIPLIER TUBE
CERENKOV COUNTER HOUSING

Fig. 10

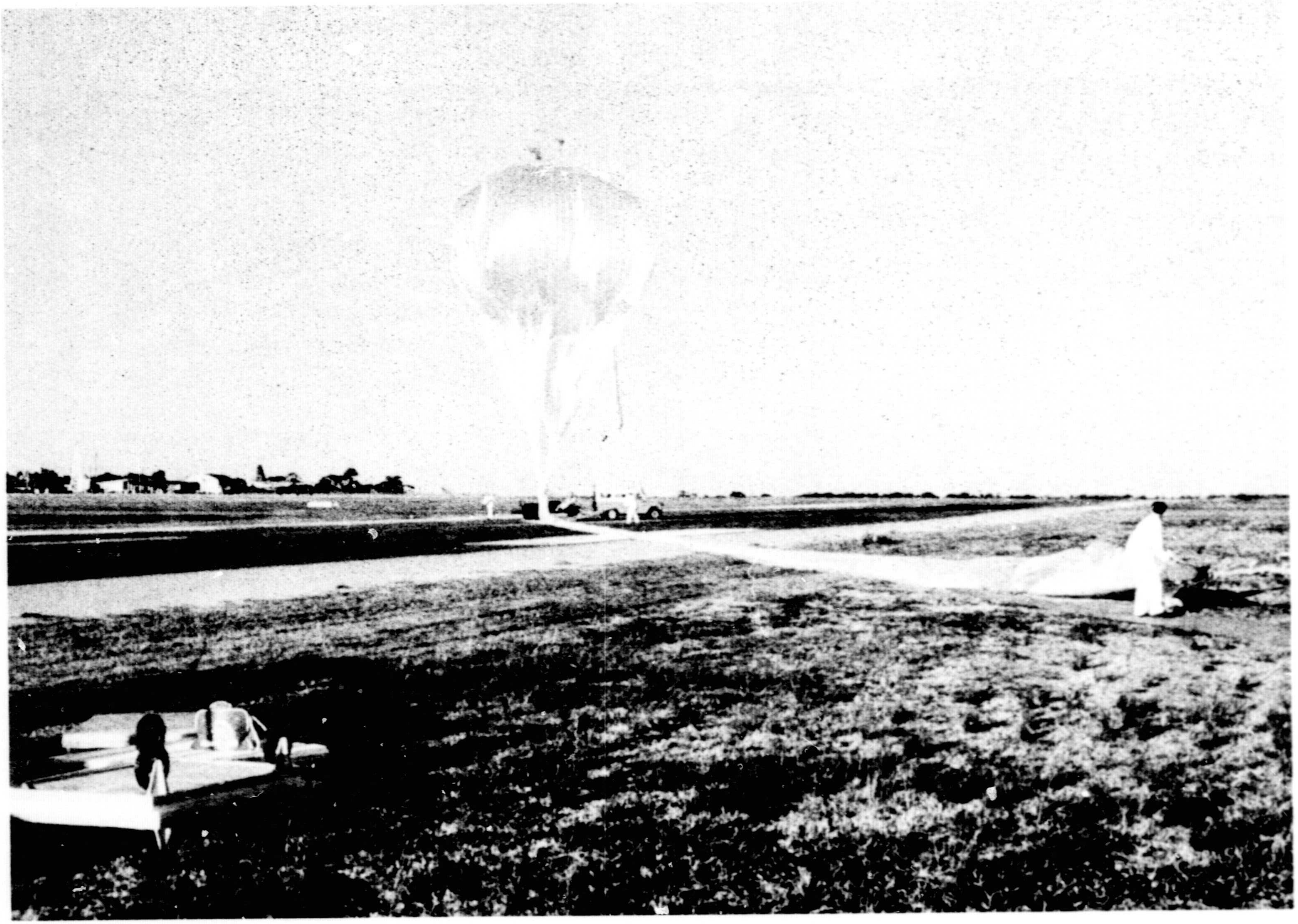


Fig. 11

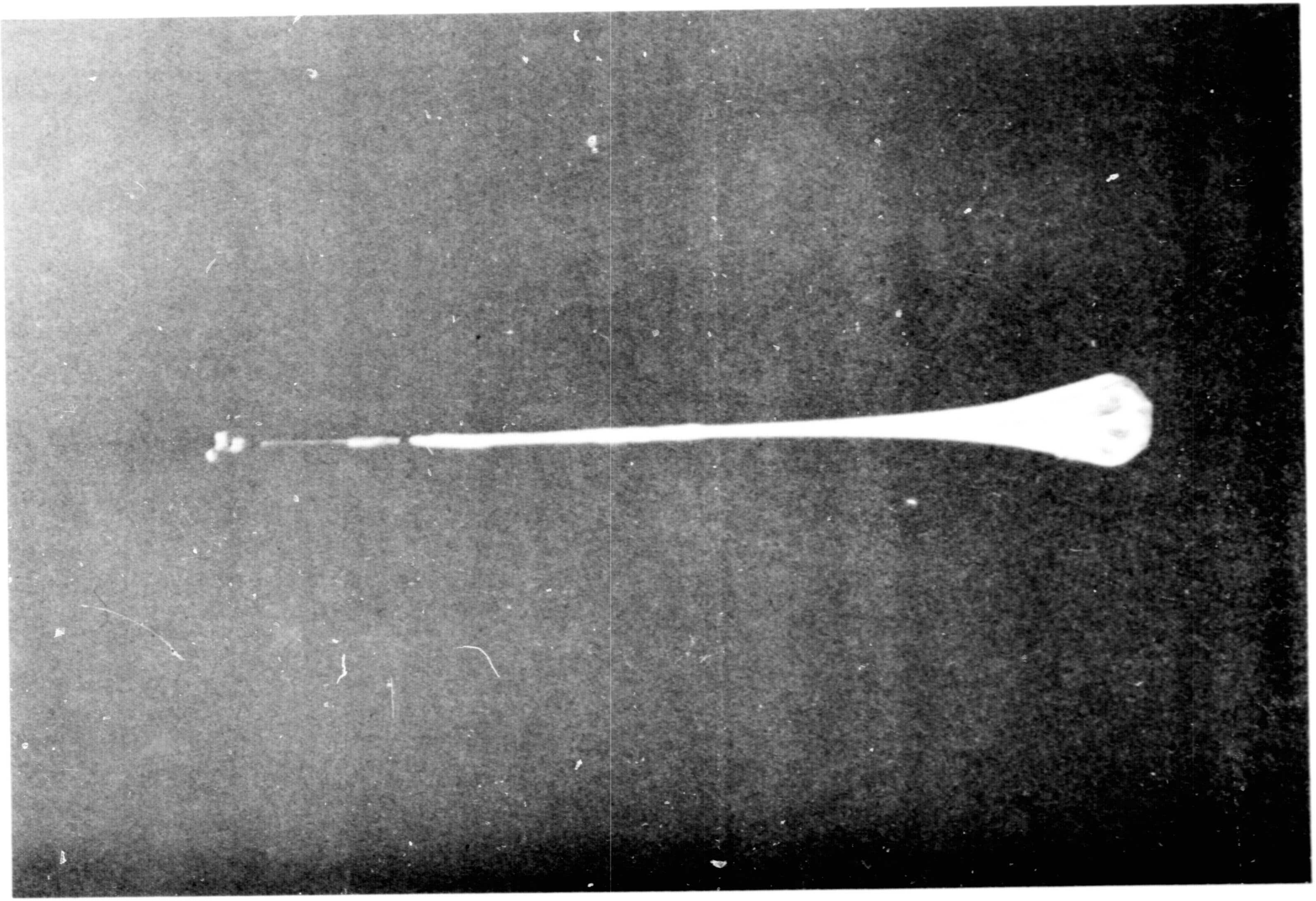


Fig. 12

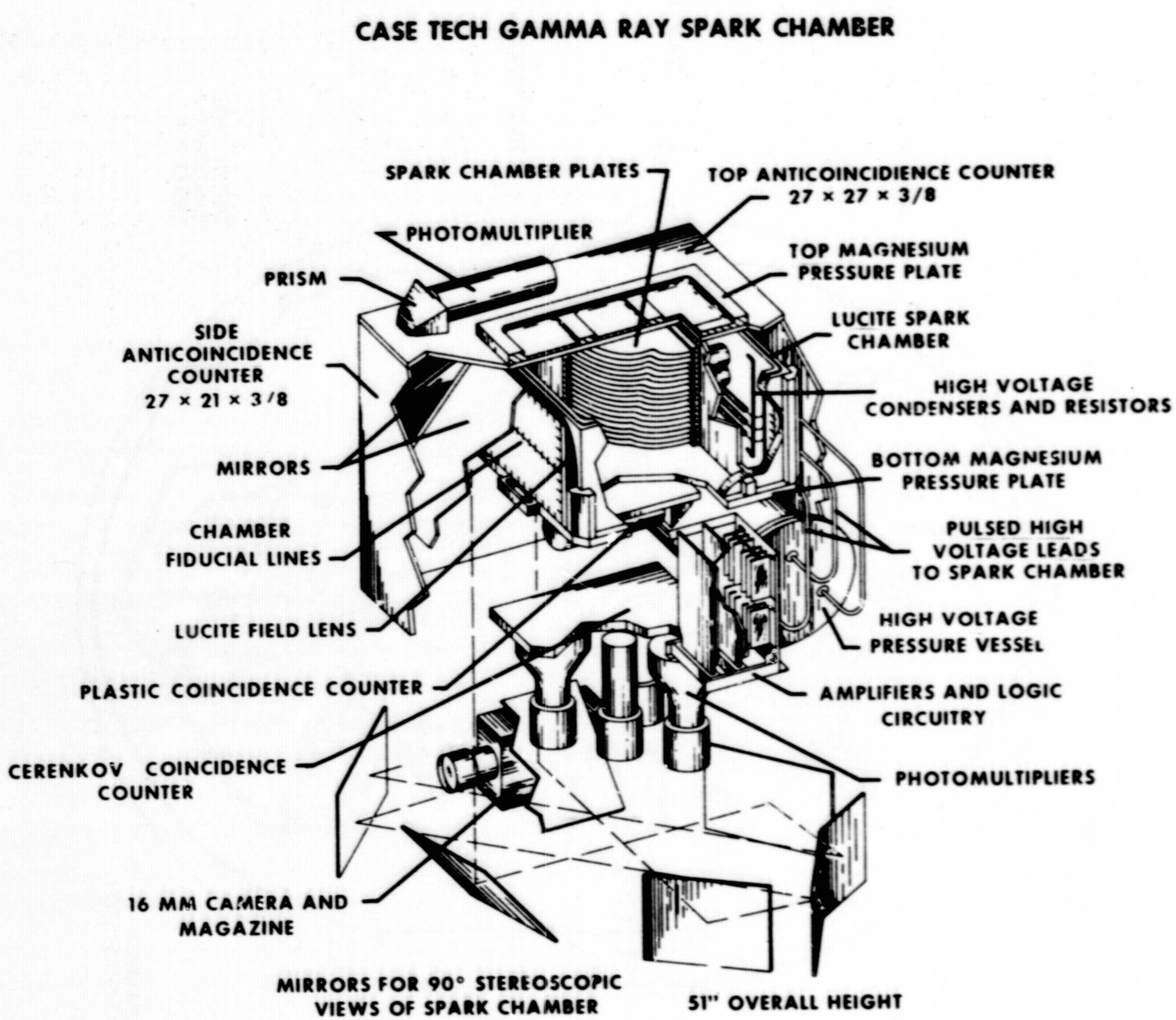
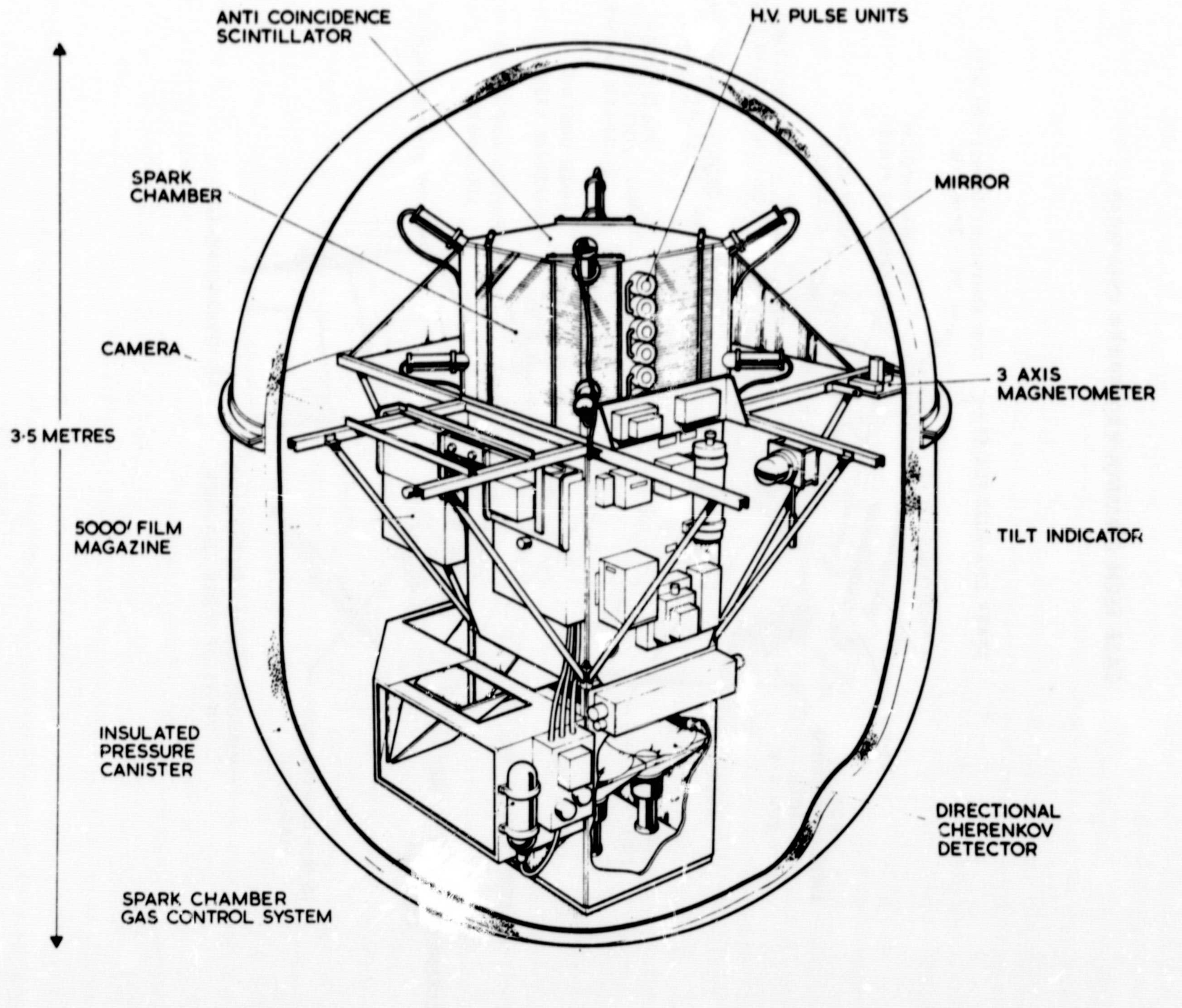
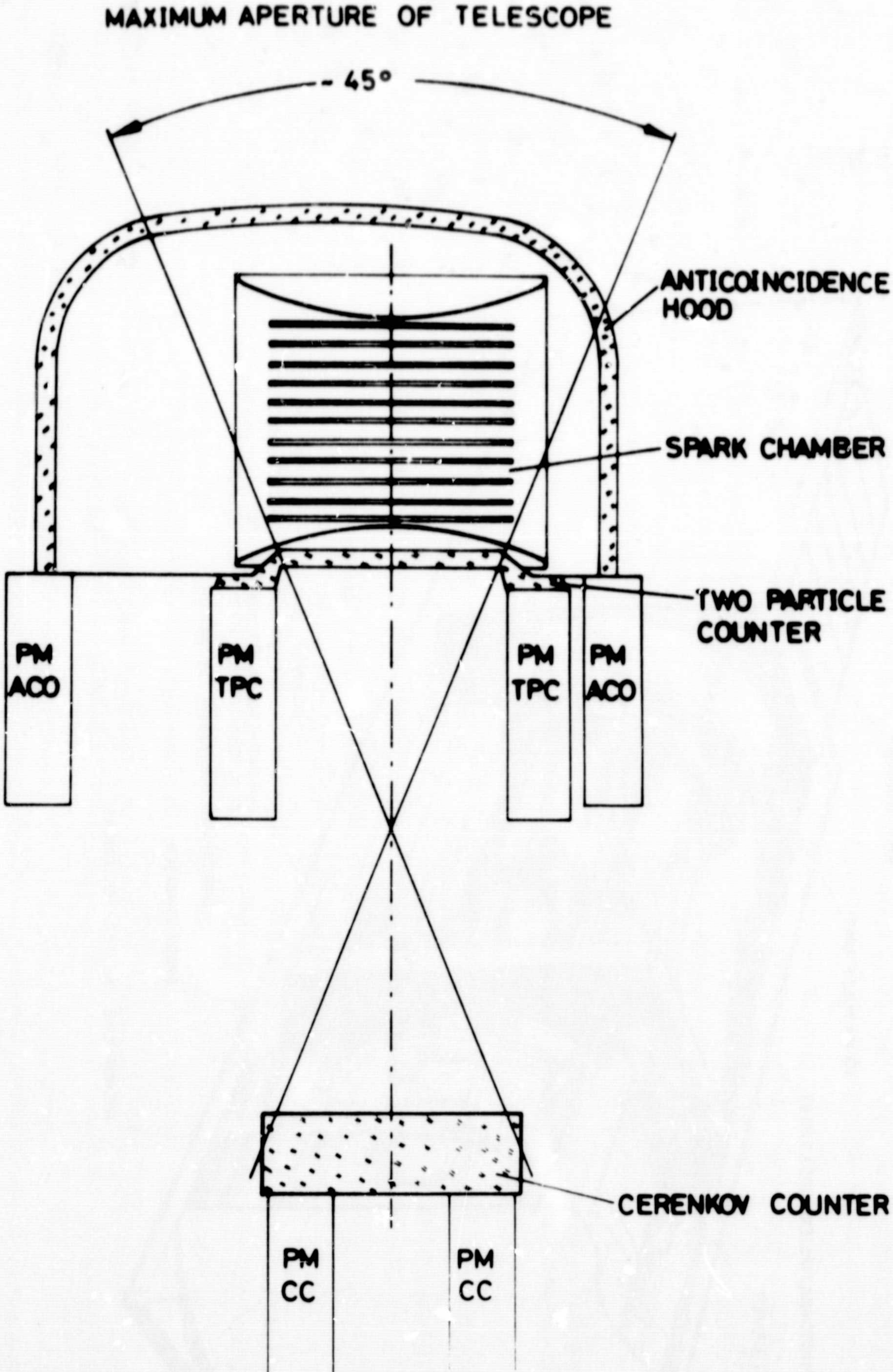

CASE TECH GAMMA RAY SPARK CHAMBER
SPARK CHAMBER PLATES
TOP ANTICOINCIDIENCE COUNTER
27 × 27 × 3/8
PHOTOMULTIPLIER
PRISM
TOP MAGNESIUM
PRESSURE PLATE
SIDE
ANTICOINCIDENCE
COUNTER
27 × 21 × 3/8
LUCITE SPARK
CHAMBER
HIGH VOLTAGE
CONDENSERS AND RESISTORS
MIRRORS
BOTTOM MAGNESIUM
PRESSURE PLATE
CHAMBER
FIDUCIAL LINES
PULSED HIGH
VOLTAGE LEADS
TO SPARK CHAMBER
LUCITE FIELD LENS
HIGH VOLTAGE
PRESSURE VESSEL
PLASTIC COINCIDENCE COUNTER
AMPLIFIERS AND LOGIC
CIRCUITRY
CERENKOV COINCIDENCE
COUNTER
PHOTOMULTIPLIERS
16 MM CAMERA AND
MAGAZINE
MIRRORS FOR 90° STEREOSCOPIC
VIEWS OF SPARK CHAMBER
51" OVERALL HEIGHT

Fig. 13



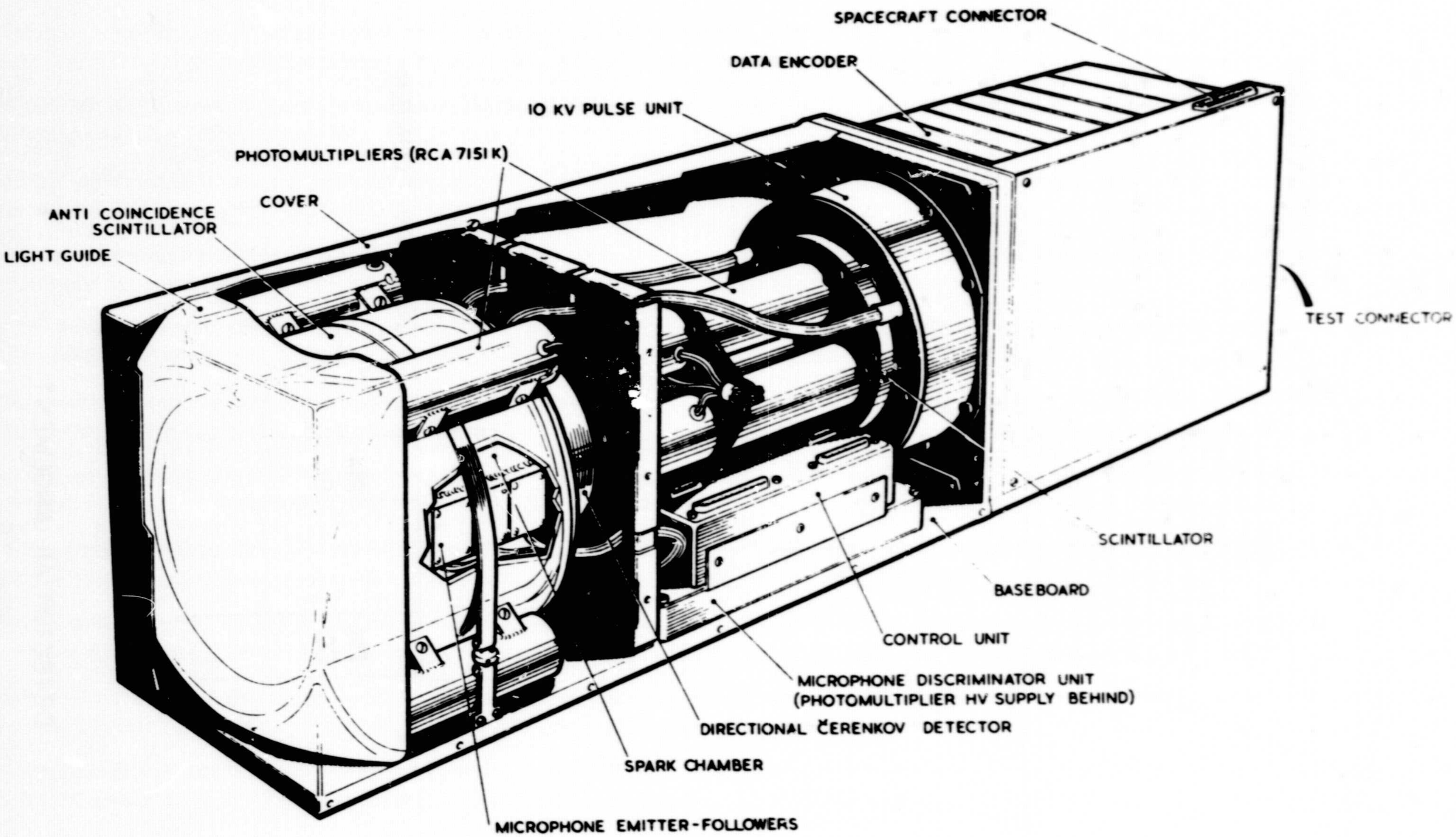
BALLOON BORNE GAMMA RAY TELESCOPE

Fig. 14



DETECTOR ARRANGEMENT

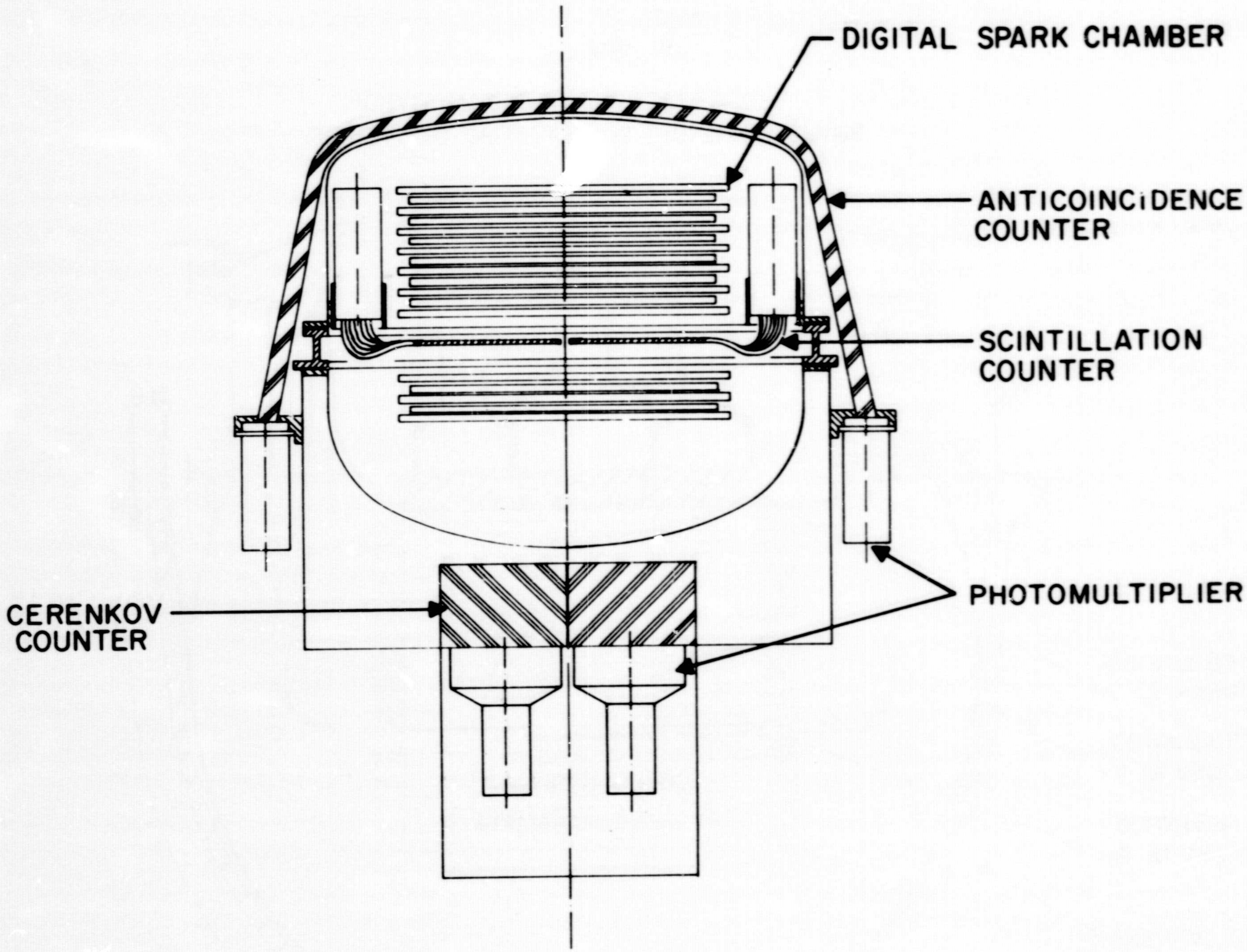
Fig. 15



GAMMA-RAY ASTRONOMY EXPERIMENT E-08

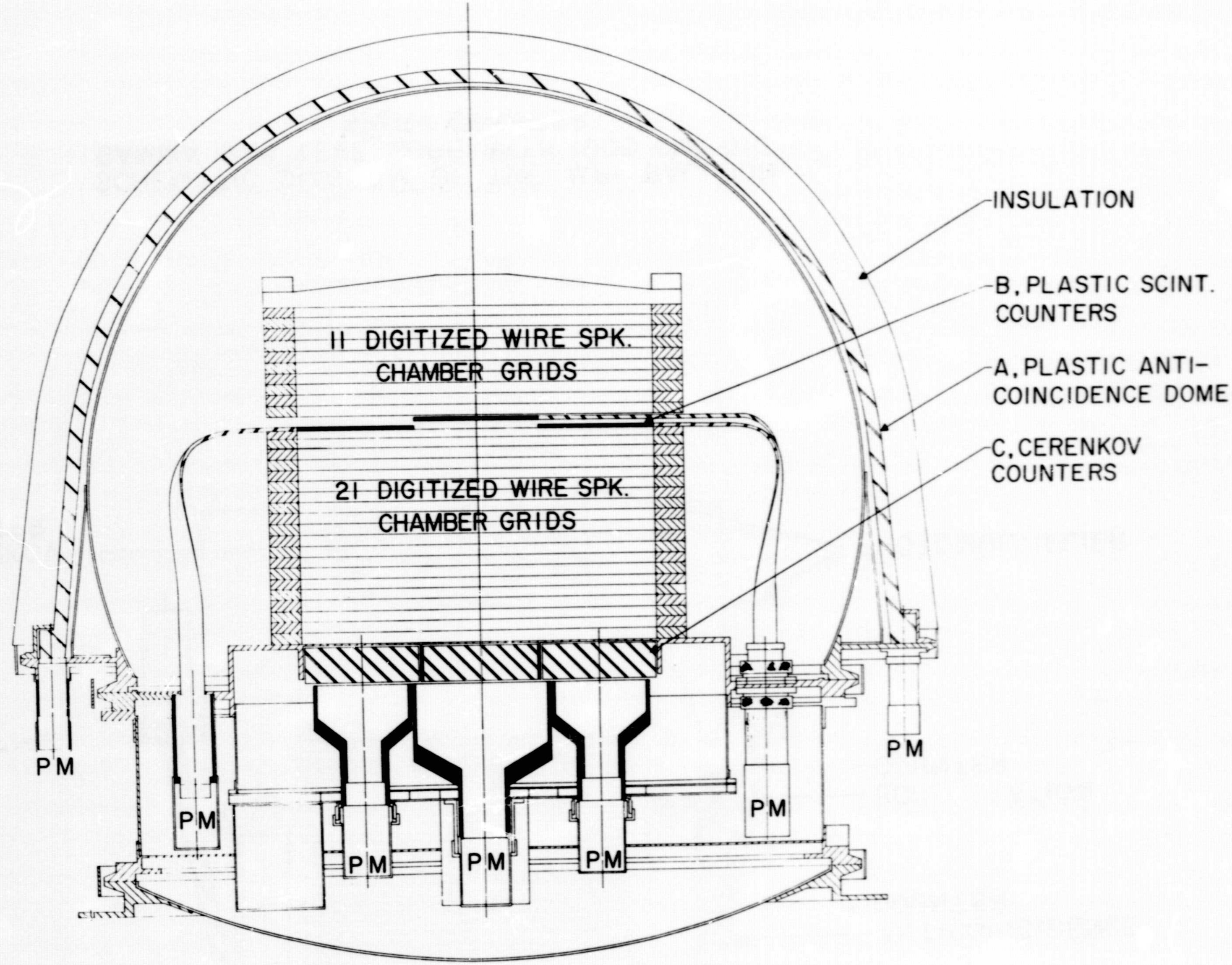
Physical Laboratory
University of Southampton

Fig. 16



SCHEMATIC DIAGRAM OF THE MPI BALLOON GAMMA RAY TELESCOPE WITH 1000 CM^2 DIG SPARK CHAMBER

Fig. 17



SCHEMATIC OF 1/2 x 1/2 M. DIGITIZED SPARK CHAMBER GAMMA RAY TELESCOPE

Fig. 18

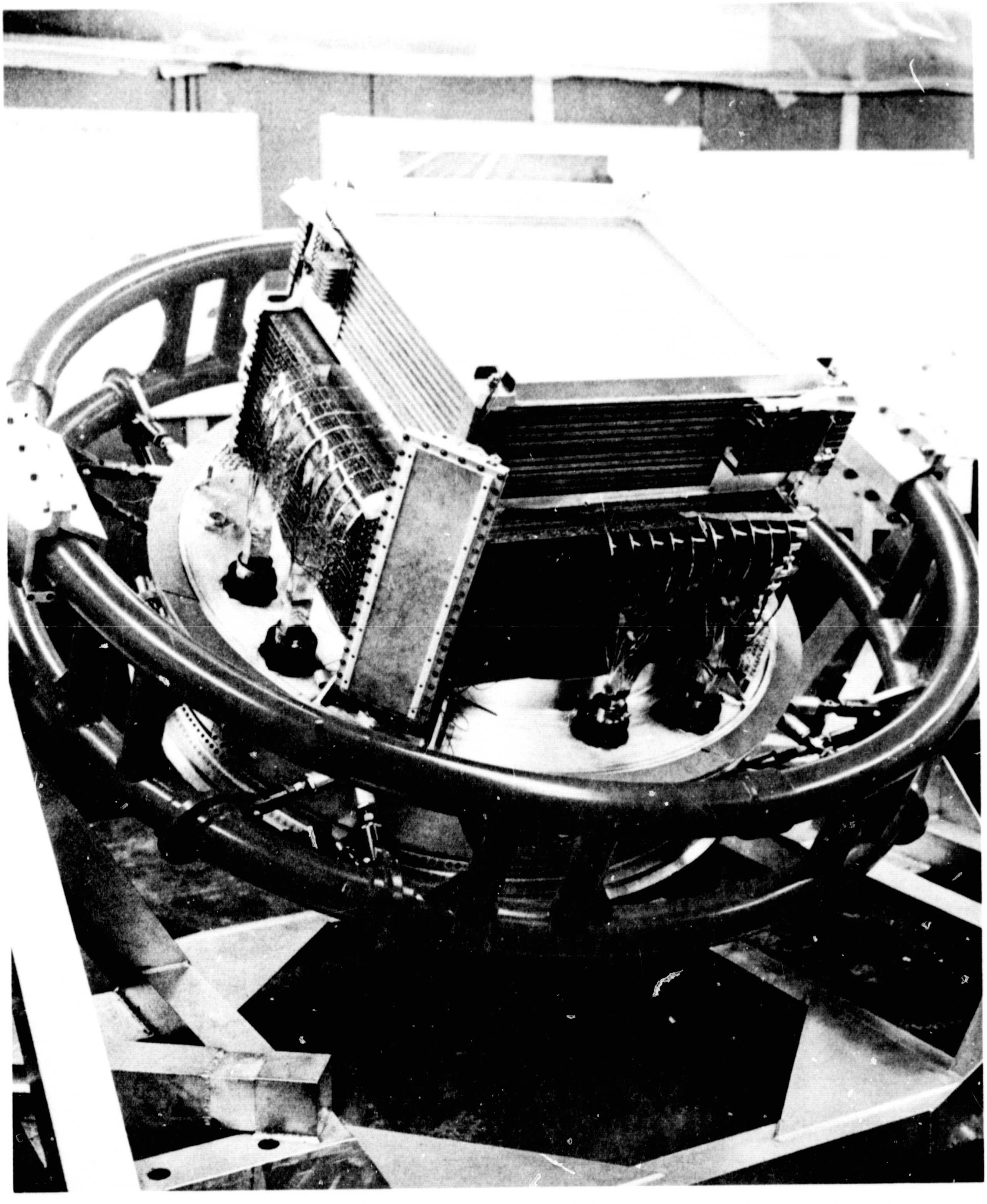


Fig. 19

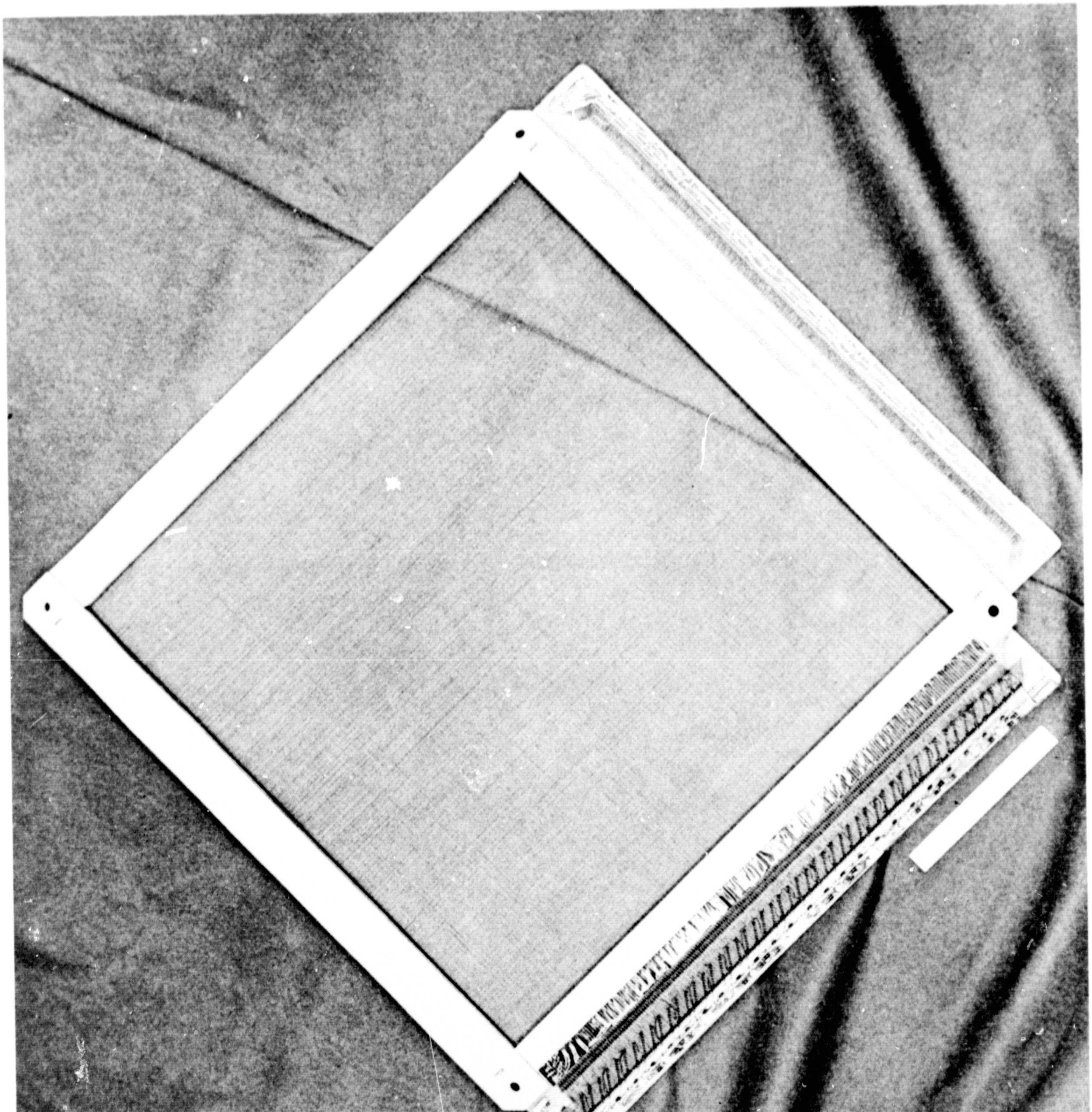


Fig. 20

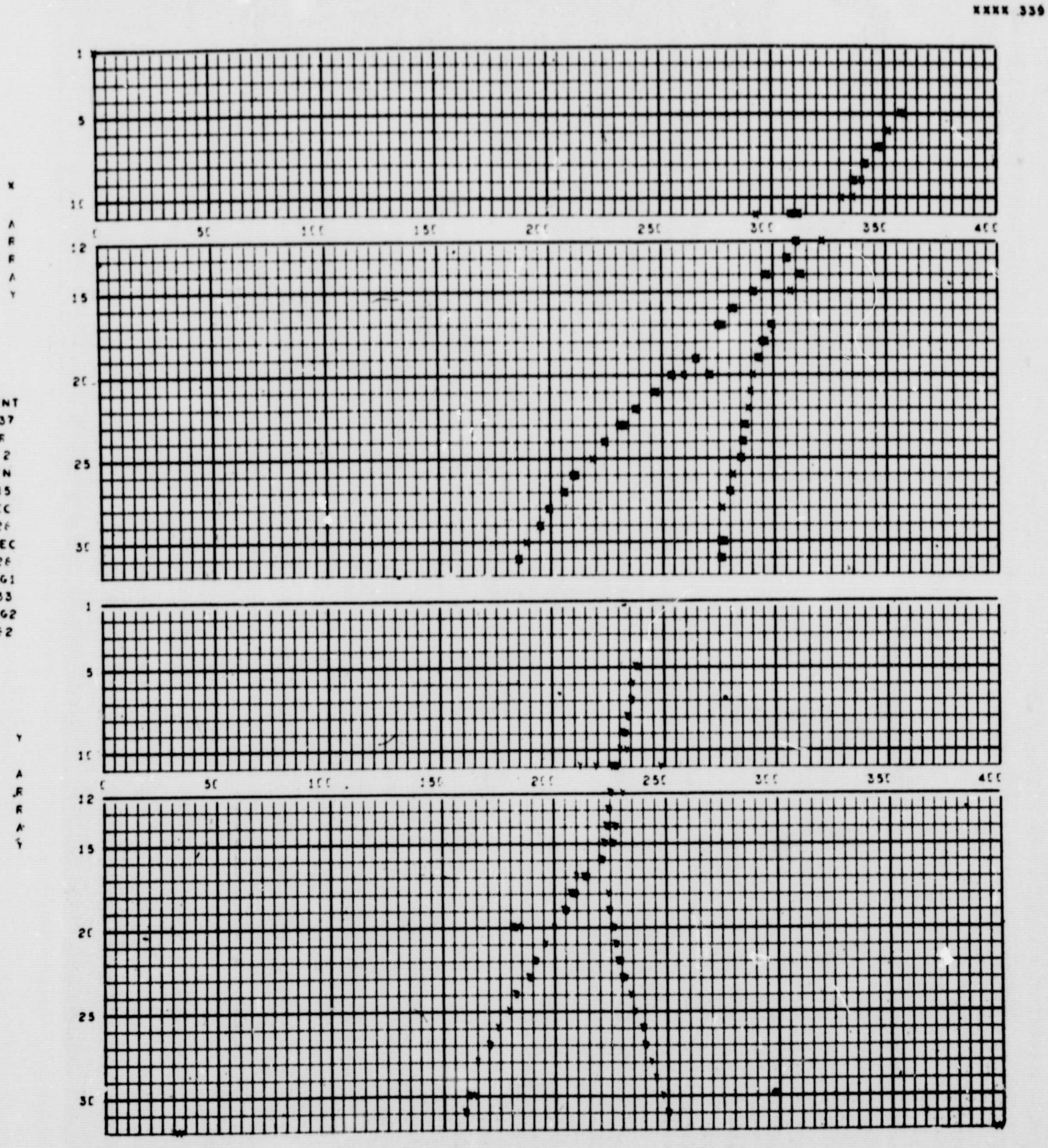

XXXX 339
X ARRAY
Y ARRAY
EVENT 1337 HR 2 MIN 35 SEC 26 MSEC 26 MAG1 133 MAG2 162

Fig. 21

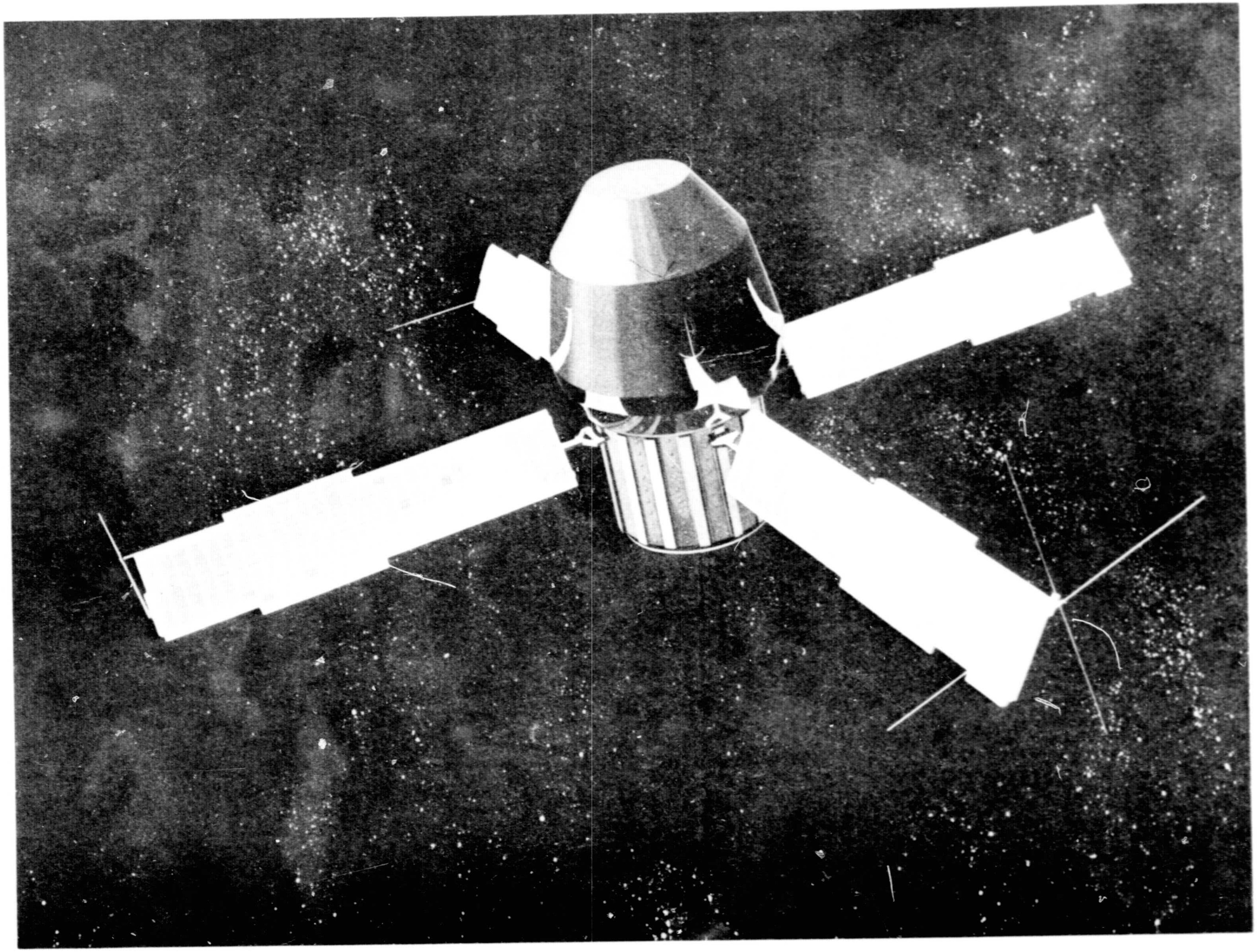


Fig. 22

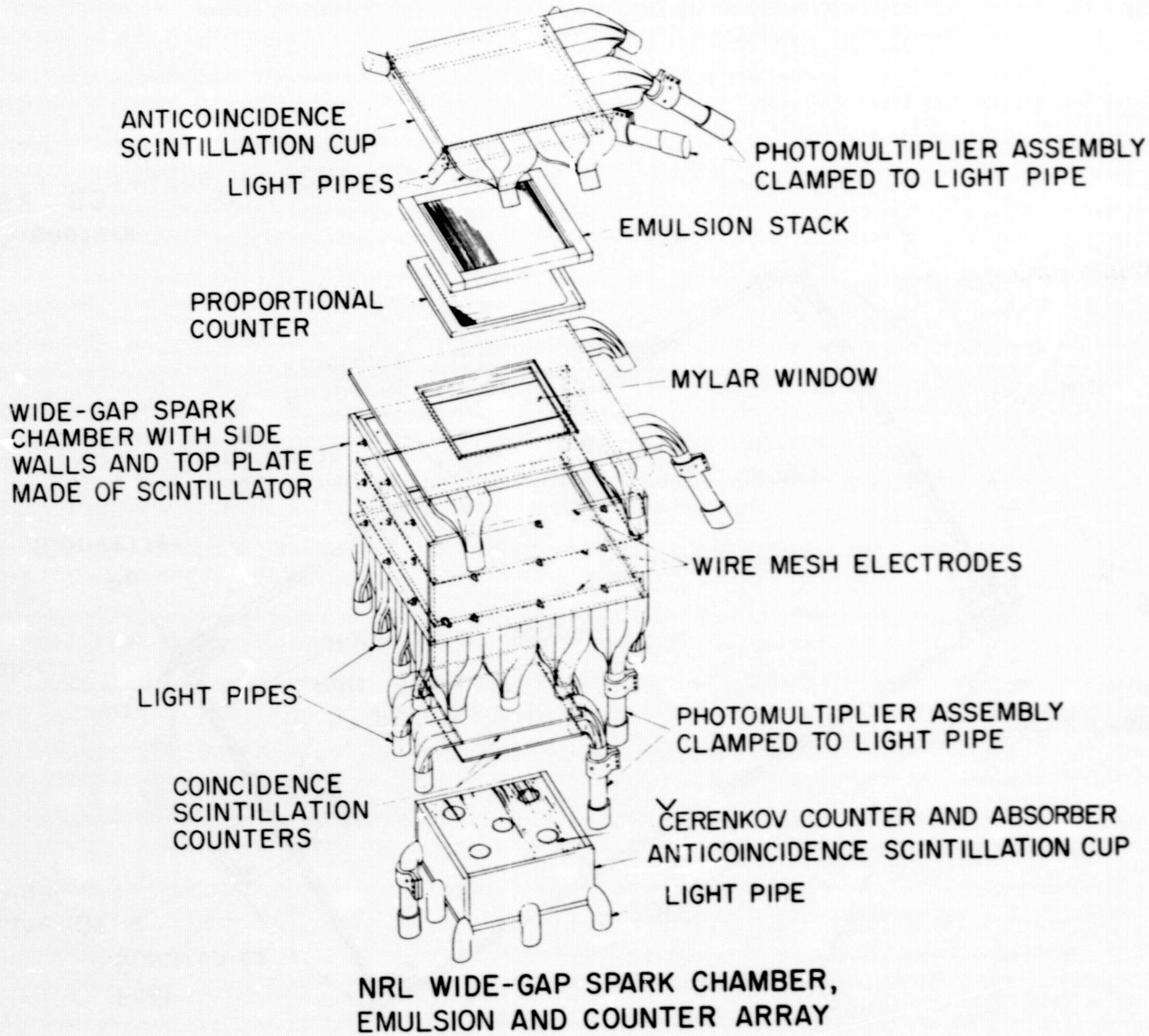

ANTICOINCIDENCE SCINTILLATION CUP
LIGHT PIPES
PHOTOMULTIPLIER ASSEMBLY CLAMPED TO LIGHT PIPE
EMULSION STACK
PROPORTIONAL COUNTER
MYLAR WINDOW
WIDE-GAP SPARK CHAMBER WITH SIDE WALLS AND TOP PLATE MADE OF SCINTILLATOR
WIRE MESH ELECTRODES
LIGHT PIPES
PHOTOMULTIPLIER ASSEMBLY CLAMPED TO LIGHT PIPE
COINCIDENCE SCINTILLATION COUNTERS
ČERENKOV COUNTER AND ABSORBER
ANTICOINCIDENCE SCINTILLATION CUP
LIGHT PIPE
NRL WIDE-GAP SPARK CHAMBER, EMULSION AND COUNTER ARRAY

Fig. 23

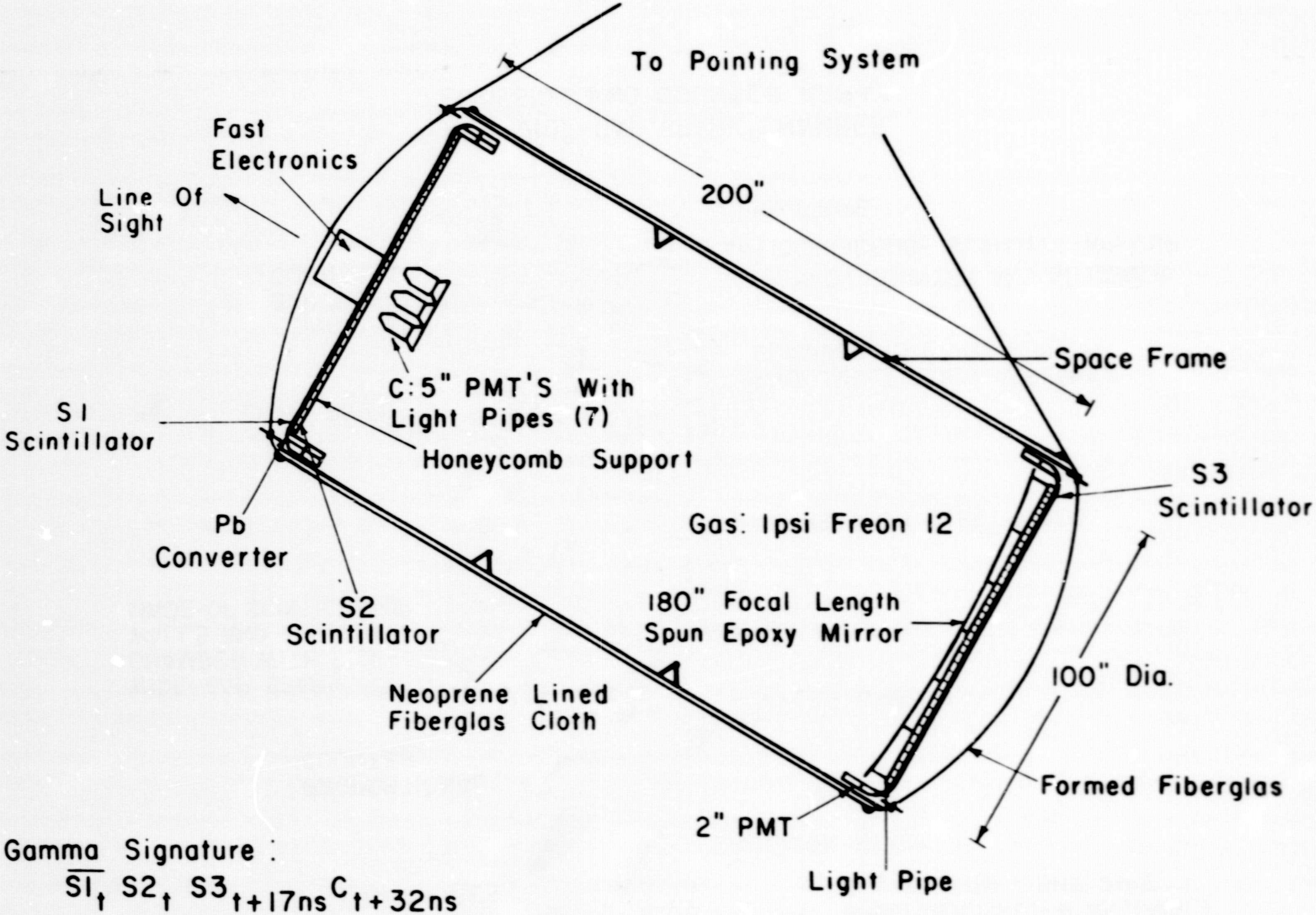

To Pointing System
200"
Fast
Electronics
Line Of
Sight
Space Frame
C: 5" PMT'S With
Light Pipes (7)
S1
Scintillator
Honeycomb Support
S3
Scintillator
Pb
Converter
Gas: 1psi Freon 12
S2
Scintillator
180" Focal Length
Spun Epoxy Mirror
100" Dia.
Neoprene Lined
Fiberglas Cloth
Formed Fiberglas
2" PMT
Light Pipe
Gamma Signature :
$\overline{S1_t}\ S2_t\ S3_{t+17ns}\ C_{t+32ns}$

Fig. 24

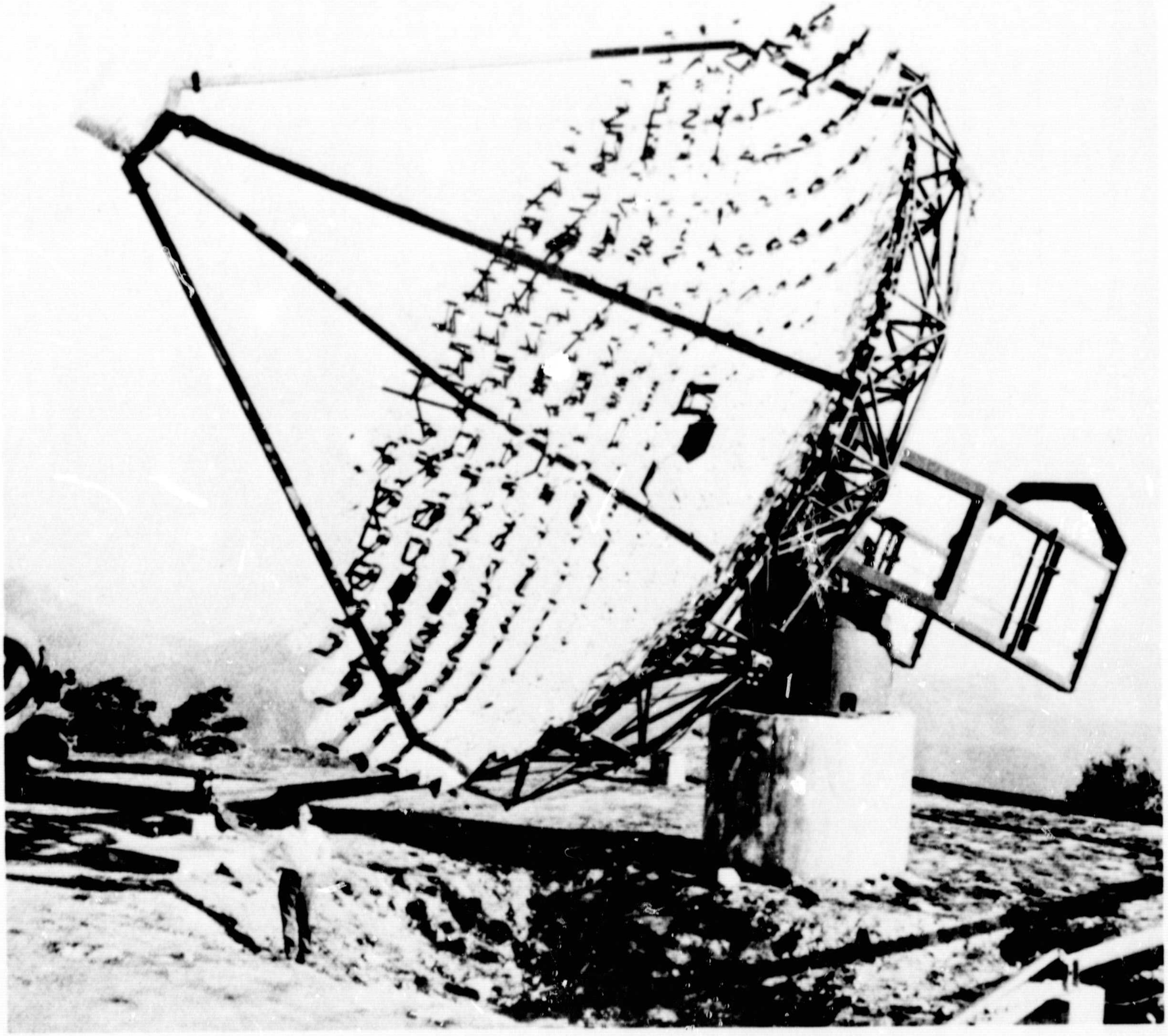


Fig. 25